



Waipaoa River Catchment Modelling

Gisborne District Council and Horticulture New Zealand

SOURCE Modelling Report

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Executive Summary

Gisborne District Council (GDC), Horticulture New Zealand, Eastland Wood Council and Federated Farmers have jointly funded a development phase catchment surface water and water quality model for the Waipaoa and Taruheru Rivers.

A significant amount of data for the Waipaoa and Taruheru Catchments was provided from GDC. This was their best available dataset at the time, and covers a range of items including flow and water quality records, GIS layers (cropping and landuse), consented water take information (irrigation) and literature (reports). Additional information from external organisations were also utilised, including soil layers and drainages (SMap), stocking and landuse information (Agribase), catchment and river drainage information (REC) and gridded climate data from NIWA.

The data was used to develop a catchment-scale hydrological and water quality model using the eWater Source modelling framework. The model comprises of 50 sub-catchments, and integrates relevant landuse types (such as sheep and beef, citrus, maize, pasture) and soil drainages across the entire Waipaoa and Taruheru catchments. Spatially gridded historical rainfall and evapotranspiration data was applied to the subcatchments and landuse types, and flow was simulated using a rainfall runoff model known as the Soil Moisture Water Balance Model (SMWBM).

This runoff model has a number of hydrological parameters that convert rainfall inputs to a simulated streamflow. These parameters were calibrated against historical daily flow records from a number of sites within the Waipaoa Catchment, with the objective to have a model which can be used to predict streamflow and model future scenarios such as landuse change or intensification.

The calibration results of the flow model indicated a very good representation between observed and simulated flows (model fit) at the lowland river station (Matawhero), ranging to a good model fit upstream at Kanakanaia, and a satisfactory model fit in the upper catchment (i.e. Mahaki Station). There was an observed overestimation of simulated low-moderate flows from Kanakanaia upstream, which will require further investigation and recalibration in the future, possibly to better account for surface water – ground water interactions and any surface water abstractions which may not have been captured in the current model.

Once the calibrated surface water model was completed, water quality model components were added to model nutrient loads and concentrations at various locations. The water quality constituents which were modelled were Nitrate-N ($\text{NO}_3\text{-N}$), Dissolved Reactive Phosphorus (DRP) and Ammonia-N ($\text{NH}_3\text{-N}$, commonly known as ammonia).

Monthly water quality data from river monitoring through 2003–2014 was evaluated and used to inform input parameter concentrations into the model. Data from literature studies outlining leaching rates from various landuses was also utilised, particularly from the report 'Land Management Practices and Nutrient Losses from Farms on the Poverty Bay Flats' (Gentile *et al.* 2014).

Water quality inputs (as a concentration) were applied in the model against baseflow and quickflow. Baseflow is considered to be the residual base volumes in a river, usually fed from sustained groundwater discharge, while quickflow is event based surface runoff which occurs during rainfall events. The water quality model components are referred to as Dry Weather Concentrations (DWC's, applied to baseflow) and Event Mean Concentrations (EMC's, applied to quickflow). DWC's are the average annual leaching concentrations from various landuse/soil type combinations (i.e. Citrus, Poorly Drained Soil). EMC's are the concentrations applied during a particular threshold surface runoff event.

The water quality input concentrations were applied to the simulated flow in the model. Calibration was undertaken by comparing the predicted concentration at a known monitoring site, versus the observed concentration on a monthly timestep, in line with the availability of monthly monitoring data. Manual modifications to input values within an acceptable range determined from literature were undertaken numerous times to calibrate the model. Attenuation factors were included to represent nutrient loss through sub-surface and in-stream transformations (e.g. denitrification). Due to limited data from which to determine site-specific attenuation losses, a literature review was used to determine indicative attenuation rates. These attenuation

rates were applied in the model as a straight loss reduction (i.e. 60% DRP attenuation reduced the concentration in the river by 60%).

The water quality calibration had a good to very good fit between median observed and modelled concentrations at the same stations outlined in the flow calibration above. However, the calibration indicated that the model under predicted the water quality concentrations during low and high flow events so would not be appropriate for estimating extremes in water quality such as the 95th or 5th percentile values. Further calibration (and site data collection) is required, as the current model is most likely limited by the assumptions made through flow modelling, water quality calibration and attenuation.

The final calibration slightly underestimated median nitrate concentrations (compared to observed) at the three sites. Median DRP was slightly over estimated in the upper catchment (Mahaki), however was a good fit to observed concentrations at Kanakanaia and Matawhero. Ammoniacal-N had the highest variability in simulated median concentrations, with the model overestimating at the upper catchments (Kanakanaia and Mahaki), but underestimating at Matawhero. Consequently, further calibration on Ammoniacal-N (NH₃-N) should occur in the future, as the model may be currently underestimating NH₃-N loads from lowland land use types (i.e. cropping).

However, in its current state, the model is a suitable tool to assess the relative percentage change in water quality concentrations between landuse change scenarios and to indicate potential water quality impacts at a seasonal temporal scale. Note that NH₃-N in lowland sites (i.e. Matawhero, Tuckers Road-Taruheru) may slightly under predict the % change from median results for reasons outlined above.

The calibrated baseline model was used to simulate two scenarios:

- Scenario 1: Additional irrigation development - this scenario investigated the consequences of doubling the irrigated cropping area from ~2,600 ha to 5,200 ha. Ammoniacal-N (NH₃-N), Dissolved Reactive Phosphorus (DRP) and Nitrate-N (NO₃-N) were compared.
- Scenario 2: A permitted nitrate loss level for productive landuse - this scenario investigated the effects of increasing loads of nitrate due to landuse change on flat productive land (deemed to be <15^o). The focus was on conversion to cropping, with the change in Nitrate-N concentrations observed.

Scenario 1 results for five stations have been presented in the table below. The highest increases in median annual concentrations were predicted in the Taruheru River, due to the high density of cropping. Irrigated cropping in scenario 1 only makes up ~2.2% of the total catchment area, and for this reason the % increase in concentration is significant in the Waipaoa due to its greater catchment area, higher river flow and other landuses.

Station Name	% increase in median annual concentration from doubling irrigation		
	NO ₃ -N	NH ₃ -N	DRP
Matawhero (Waipaoa R)	2.4	0.5	2.8
Kanakanaia (Waipaoa R)	0.7	0.2	0.3
Brunton (Waipaoa R)	1.3	0.3	0.6
Kaiteratahi (Waipaoa R)	1.2	0.2	0.4
Tuckers Rd (Taruheru R)	8.5	5.5	6.2

Scenario 2 showed a more significant increase in concentrations. This is to be expected, as the scenario involved determining all the productive land area under a slope of 15 degrees and changing the landuse type over four incremental area increases. The total productive landuse area (under 15 degrees) was 25,506 ha of which baseline cropping landuse made up 12,380 ha.

Cropping (maize, vegetables, citrus and grapes) areas were increased in size per subcatchment at increments of 25%, 50%, 75% and 100%. This was at the expense to other landuse types, such as sheep, beef and pasture.

A summary of the scenario 2 modelled results at five stations are presented below. This shows that the highest observed increases are at Matawhero (Waipaoa) and Tuckers Road stations (Taruheru). The results for Tuckers road shows that there is minimal change in median concentration from 50–100% increases in land area, as most of the productive land within that river catchment would have already been utilized/converted to cropping.

Station Name	% change in median annual Nitrate-N concentration from increasing crop areas			
	25% (+3,100 ha)	50% (+6,200 ha)	75% (+9,300 ha)	100% (+12,400 ha)
Matawhero (Waipaoa R)	3.5	9.8	20.4	30.5
Kanakanaia (Waipaoa R)	1.4	5.7	15.1	24.0
Brunton (Waipaoa R)	5.9	12.4	20.2	27.8
Kaiteratahi (Waipaoa R)	1.9	6.5	15.4	24.0
Tuckers Rd (Taruheru R)	10.5	24.3	26.4	29.1

The current Source model represents the first phase of developing a flexible catchment management tool for GDC, that can be expanded on as new data and science becomes available. The current model is fit-for-purpose with regards to a broad understanding of the mechanisms that influence the hydrology and water quality of the Waipaoa catchment. On-going application and revision of the model will ensure that it continues to be responsive to the evolving needs of GDC in terms of continuous model refinement and benchmarking and new scenario analysis. Learnings from the first phase of model development have identified a number of model enhancements:

- Further flow calibration and validation for a range of gauging sites, particularly to identify issues with over representation of low to moderate flows.
- Better characterisation of surface water abstractions, which may be the cause for the difference in calibration fits between Kanakanaia and Matawhero Stations.
- Integration of Total Suspended Solid (TSS) data once data quality reviews have been finalised by GDC.
- Development of a 3D groundwater model (i.e. MODFLOW) which integrates with the surface water Source model, to better capture any ground/surface water interactions (and abstraction).
- Further research into nutrient attenuation in the Waipaoa Catchment, to better understand the removal processes which may be occurring from a range of factors (such as sediment generation, deep groundwater storage to biological removal).

Over time as these issues are rectified, the model will provide a robust method for evaluating landuse change and help in planning decisions at a catchment scale. This will be beneficial to the wider Gisborne Region in ensuring sustainable development that benefits the local economy, while actively aiming to increase environmental health, particularly relating to water quantity and quality.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to develop a surface water quantity and quality model of the Waipaoa River catchment, in accordance with the scope of services set out in the contract between Jacobs and Horticulture New Zealand. That scope of services, as described in this report, was developed by Horticulture New Zealand, Gisborne District Council (GDC), Eastland Wood Council and Federated Farmers.

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1. Introduction

This report provides a technical overview on the development of a land use and nutrient loss model for the Greater Waipaoa River Catchment (including the Taruheru River and tributaries). The model was built on the eWater Source platform, which is a semi-distributed catchment modelling framework that operates on a daily time step (Welsh et al. 2012). It conceptualises a range of catchment processes using subcatchments which are composed of Functional Units (FU) that generally represent areas of common hydrology, such as land use or soil type. Daily rainfall-runoff modelling, calibrated to spatially distribute historical climate, enables the representation of spatial and temporal variability in runoff and nutrient generation (or leaching) from different farming enterprises and non-agricultural land across the Waipaoa catchment.

The key advantage of this model is that it integrates the farm scale processes of nutrient generation with surface and groundwater flow pathways and that it runs on a daily time step and hence is capable of simulating temporal and climate driven variations.

This model build was funded collaboratively, led by Horticulture New Zealand Ltd and Gisborne District Council (GDC), with support from Eastland Wood Council and Federated Farmers. The approach was an initial Phase I catchment model which was calibrated to one primary lowland gauge, to determine surface flow and nutrient loading from a range of landuse and soil drainage types. The model utilised available monitoring data, literature and local modelling results (SPASMO Plant and Food crop modelling for the Poverty Bay Flats- Gentile *et al.* 2014).

The model can be further developed and enhanced in the future to allow improved surface water calibration, the integration of a groundwater model such as MODFLOW to capture catchment nutrient and flow dynamics as effectively as possible, as well as inclusion of new data sources when they become available. Currently this represents a first pass approach utilising as much available data as possible (i.e. Agribase, S-map, Cropping layers etc) to reduce requirements for significant rebuilds in the future, simplifying these for calibration where required.

2. Data Review

A significant data review was undertaken of the GDC flow and water quality sites. These are summarised in the tables below, with a map of the key water quality and flow sites presented in Figure A1 in Appendix A.

Table 2.1 presents the flow monitoring sites within Waipaoa. Table 2.2 presents the sites of which water quality samples are collected.

Most water quality sampling occurred routinely on a monthly basis from 2003 onwards. Total Suspended Solids (TSS) data has been collected for a number of sites with durations longer than the nutrient data collection.

The water quality review focussed on identifying data gaps, data periods and compilation for input into Source. It has been assumed the quality of the raw data provided to Jacobs is acceptable and represents the best available information at the time of the model development.

Table 2.1 : GDC flow monitoring sites

GDC Water Level Monitoring Sites	WQ site also?	Data period	Data Type
Mangatu River at Omapere Station	Y	1984-2014	Flow and WL Time series
Te Arai River at Pykes Weir	Y	1984-2015	Flow and WL Time series
Waikohu River at Mahaki Station	Y	1980-2014	Flow and WL Time series
Waingaromia River at Terrace Station	Y	1993-2014	WL Data (and rating curve)
Waipaoa River at Kanakanaia	Y	1958-2014	Flow and WL Time series
Wharekopae River at Rangimoe	Y	1993-2014	WL Data (and rating curve)
Waipaoa River at Matawhero Bridge	-	1973-2014	Flow and WL Time series
Taruheru Trib at Courtneys Br	-	1993-2014	Flow and WL Time series
Te Arai River at SH2 Br	-	2012-2014	WL Data (no rating curve)
Waihora River at No.3 Br	-	1987-2014	Flow and WL Time series
Waikakariki Stream at Kirkpatrick Bridge	-	2013-2014	WL Data (and rating curve)
Waipaoa River at Te Hau Station Rd Br	-	2014	WL Data (limited rating curve)
Waipaoa River at Waipaoa Station	-	1980-2014	Flow and WL Time series
Waru Stream at McLaurin Bridge	-	1996-2014	Flow and WL Time series
Taruheru River at Campion Rd	-	2013-2014	WL Data (no rating curve)
Waipaoa River at Kaiteratahi Bridge	-	1989-2014	Flow and WL Time series

Table 2.2 : GDC water quality monitoring sites

GDC Water Monitoring Sites	Flow Site also	Period	Comments
Mangatu River at Omapere Station	Y	1984-2014	Limited TP and TN and DIN (1-3 samples). Nitrate-N/nitrite, ammonia, DRP and TSS data available, monthly from 2003
Te Arai River at Pykes Weir	Y	2003-2014	TSS from 1984, Nitrate-N, ammonia, DRP monthly from 2003. Limited and Patchy TP/TN data
Waikohu River at Mahaki Station	Y	1984-2014 (patchy)	Limited TN and TP. Nitrate-N/nitrite, ammonia, DRP and TSS data available, monthly from 2003

GDC Water Monitoring Sites	Flow Site also	Period	Comments
Waingaromia River at Terrace Station	Y (WL data only)	1990-2014	Limited TN and TP. Nitrate-N/nitrite, ammonia, DRP and TSS data available, monthly from 2003
Waipaoa River at Kanakanaia	Y	1978-2014	Limited TN and TP. Nitrate-N/nitrite, ammonia, DRP and TSS data available, monthly from 2003
Wharekopae River at Rangimoe	Y (WL data only)	1994-2014	Limited TN and TP. Nitrate-N/nitrite, ammonia, DRP and TSS data available, monthly from 2003
Waipaoa River at Matawhero Bridge	Y	1979-2014	Limited TN and TP. Nitrate-N/nitrite, ammonia, DRP and TSS data available, monthly from 2003
Waipaoa River at Waipaoa Station	Y	1980-2014	TSS data only
Waipaoa River at Kaiteratahi Bridge	Y	1990-2014	TSS data only
Taruheru River at Tuckers Rd Bridge	-	1981-2014	Limited TN and TP. Nitrate-N/nitrite, ammonia, DRP and TSS data available, monthly from 2003
Whakaahu Stream at Brunton Rd 19704009	-	2003-2014	Limited TN and TP. Nitrate-N/nitrite, ammonia, DRP and TSS data available, monthly from 2003

Additionally, the following data was collected to inform the Source model configuration:

- Digital Elevation Model (DEM) to define catchments, drainages and topography of the Waipaoa
- Landuse and spatial GIS data from:
 - GDC- Poverty Bay Flats cropping layer from 2008-2014
 - ASUREQuality – Agribase 2016 landuse layer which provided significant coverage (and stocking rates), useful for the upper catchment
 - Soil data (and drainages) from S-Map,
- Actual water take records from surface water consents, through 2008-2014 in time series,
- Groundwater bore data—to feed into Phase II of modelling, and
- Plant and Food (P & F) Nutrient Study Report using SPASMO modelling for cropping leaching rates in Poverty Bay Flats (Gentile et al. 2014) (referred to from now on as the P & F Report).

3. Model Information

3.1 Sub-catchments

A DEM was used to determine sub-catchments within the Waipaoa and Taruheru. A total of 50 catchments were delineated, totalling 2,264 km². Manual delineations were undertaken to ensure catchments with flow gauges were accurately represented by their realistic drainage area, critical to calibration and load assessments.

Figure A1 in Appendix A presents these catchments while Table 3.1 presents the catchment areas.

Table 3.1 : Catchment Areas and ID

ID	Area (km ²)	ID	Area (km ²)
1	101.8	26	68.5
2	6.9	27	46.1
3	5.1	28	43.7
4	12.0	29	55.5
5	42.9	30	39.7
6	57.6	31	41.4
7	79.4	32	39.9
8	34.0	33	39.1
9	71.2	34	26.5
10	102.8	35	39.3
11	89.5	36	20.4
12	92.8	37	32.1
13	38.9	38	48.1
14	40.9	39	39.0
15	35.9	40	57.0
16	58.9	41	21.2
17	19.2	42	18.9
18	49.9	43	84.4
19	44.0	44	111.7
20	30.9	45	38.6
21	41.4	46	22.4
22	35.5	47	27.7
23	41.1	48	42.6
24	19.4	49	8.2
25	77.9	50	30.9

3.2 Climate (Rainfall and Evapotranspiration)

Climate data was derived from NIWA's virtual climate station (VCS). The data for Waipaoa was available from 1974–2014 and included daily rainfall and evapotranspiration.

VCS is gridded data and interpolates actual data observations into grid resolutions, which is useful for spatial distributions of rainfall in hydrological modelling, particularly with large catchments such as the Waipaoa which experience significant orographic rainfall effects.

3.3 Functional Units

There were 39 FU's in total, including waterbody as one FU. The FU's were grouped into 4 main categories for flow calibration and load modelling, each with two drainage types. The corresponding areas and % of total area are presented in Table 3.2. The FU's are also presented in Figure A2 in Appendix A.

Well drained Sheep, Beef, Pasture and Forestry made up ~91% of the total catchment area. The incorporation of a large number of functional units allows future modelling to revise flow and nutrient calibrations as data becomes available, and also facilitates scenario analysis.

Table 3.2 : Functional Unit Groups and Corresponding Areas

Group	Soil Drainage	Area (km ²)	% Total
Crops	Poor D	40.4	1.8%
	Well D	87.4	3.9%
Forest	Poor D	3.4	0.2%
	Well D	511.0	22.6%
Pasture, Sheep and Beef	Poor D	46.9	2.1%
	Well D	1547.8	68.4%
Urban	Normal	20.8	0.9%
Water	N/A	6.1	0.3%

3.3.1 Landuse Types

Landuse types were determined from the P & F report, Agribase Stocking GIS layers and New Zealand Land Resource Inventory (LRI). There were over 24 landuse and soil combinations in the P & F report which was refined to seven groups for SPASMO modelling.

For Source modelling, the seven groups from the P & F report (excluding pasture) was further refined to Maize, Vegetables, Grapes and Citrus and makes up the Crops group in Table 3.2. Kiwifruit, Lettuce/Broccoli and Squash were grouped as vegetable given their similar drainage and leaching values.

The Agribase layer provided byASURE Quality had a total of 29 landuse types across the wider Gisborne Region. For the purposes of Source modelling, the Agribase layer was used to fill in data gaps for the upper catchments.

The landuse was refined down into six categories, which included Sheep, Beef, Sheep and Beef (described below), Native Forestry, Plantation Forestry and Other. Other represents all other landuses such as Deer, Pig, Dairy and poultry were grouped together into 'Other' group as the combined areas were small in relation to the rest of the catchment.

The Sheep, Beef and Sheep and Beef categories were defined by utilising Agribase's stocking unit data, available at the farm scale. All Beef and Sheep stock units were normalised to an 'equivalent stock unit' or Ewe equivalent, which allows comparison of different animal types by representing stock as a breeding ewe. This approach followed Waikato Regional Council's (2016) Stock Density methodology, outlined in Table 3.3. This effectively allowed three categories to be defined for future modelling, particularly around nutrient allocations to sheep or beef farms (which in the current model are lumped with the same leaching values). The categories are described in Table 3.4.

Table 3.3 : Agribase stock unit conversion factors (WRC 2016).

Farm Type	Class	Stock Units (SU) or ewe equivalent	Percent of each stock 'typically' found on farms (%)
Dairy	Dairy Cows	7	73.1
	Dairy Replacements	4.25	24.5
	Other (bulls etc)	5.5	2.4
Beef	Beef Cows	5.5	21.5
	Beef Dry	4.75	57.2
	Beef Replacements	4	14.4
	Other	5.5	6.9
Sheep	Breeding Ewes	1	67.6
	Sheep Dry	0.8	13.8
	Sheep replacements	0.7	5.9
	Other	0.8	12.7
Deer	Hinds	1.9	49.9
	Deer for Meat	1.8	30.2
	Stags for velvet	2.1	5.3
	Other	1.8	14.6

For example, the total stock units for dairy stock were calculated using the following formula:

$$\text{Dairy Stock Units} = (0.731 \times \text{Dairy numbers} \times 7) + (0.245 \times \text{Dairy numbers} \times 4.25) + (0.024 \times \text{Dairy numbers} \times 5.5).$$

Table 3.4 : Agribase equivalent stock unit categories.

Categories	Description	Beef	Sheep	Count	Proportion of farms in category
1	70%beef, 30%sheep	70-100%	0-30%	99	29%
2	50/50	30-70%	30-70%	177	52%
3	30% beef, 70% sheep	0-30%	70-100%	67	20%
Other	All other Landuses (deer, dairy etc)	N/A			

When merged with the P & F cropping layer, this created a single landuse layer for the entire Waipaoa and Taruheru catchments totalling 13 landuse types.

Table 3.5 : Landuse types and groupings

Landuse Type	Group	Group Name
Citrus	1	Crops
Grapes		
Maize		
Vegetables		
Native Forest	2	Forest
Plantation Forest		
Pasture	3	Pasture, Sheep and Beef
Sheep		
Beef		
Sheep and Beef		
Other (deer, dairy etc.)		
Urban	4	Urban
Waterbody	5	Water

3.3.2 Soil Drainage

Soil drainage for the FU's was derived from a national database, known as S-Map (Landcare Research 2016). This is a digital GIS soil coverage map which has grouped drainage classes, including:

- Very Poor (Class I)

- Poor (Class II)
- Imperfect (Class III)
- Moderately Well (Class IV)
- Well (Class V)

For simplicity and to reduce the number of FU and consequently calibration parameters in rainfall runoff modelling, only two soil drainages were utilised in modelling. These were Poor (Class I & II) and Well Drained (Class III–V). Well drained soil represented ~95% of the catchment area.

3.3.3 Irrigation

An irrigation layer was also applied to landuse and soil drainage layers. This utilised an existing GIS layer from GDC which showed polygon areas where irrigation was occurring. A spatial intersect was applied to incorporate irrigated versus non irrigated landuse types in the FU list.

An example of this in the Source modelling layer would be Maize_PoorD_NonIrr or Maize_WellD_Irr.

3.4 Consented Water Takes

Metered consented take data was provided by GDC from 2008 to 2014. This data outlined the metered water take consumptions from each consent on a monthly basis. The consents were grouped into 19 main catchments zones to agglomerate the time series of abstraction for simplification in Source modelling. This was refined to 16 catchments as three catchments had no abstractions occurring. See Figure A3 in Appendix A.

Significant data processing was required, as consent numbers changed over time or had split consents, yet the abstraction locality remained the same. Some consented takes were in GIS (~70%) while others had to be determined manually through address verification. In total, 78 surface water takes with abstraction data were agglomerated.

Water takes were applied in Source to the most downstream reach of the designated catchment zone.

3.4.1 Water Demand Timeseries

The monthly agglomerated water takes for each of the 16 catchments were converted to average daily abstraction. See Figure 3.1. No water abstraction data was available prior to 2008 however it is likely surface water abstractions were occurring.

For simplicity, it could be assumed no takes had occurred, however this would be unrealistic and may impede flow calibration. The approach undertaken was to derive average monthly demand for each catchment, based on 3 years of the earliest consented water abstraction data (2008-2010). This average rate was then applied to the long term time series from 1972–2008.

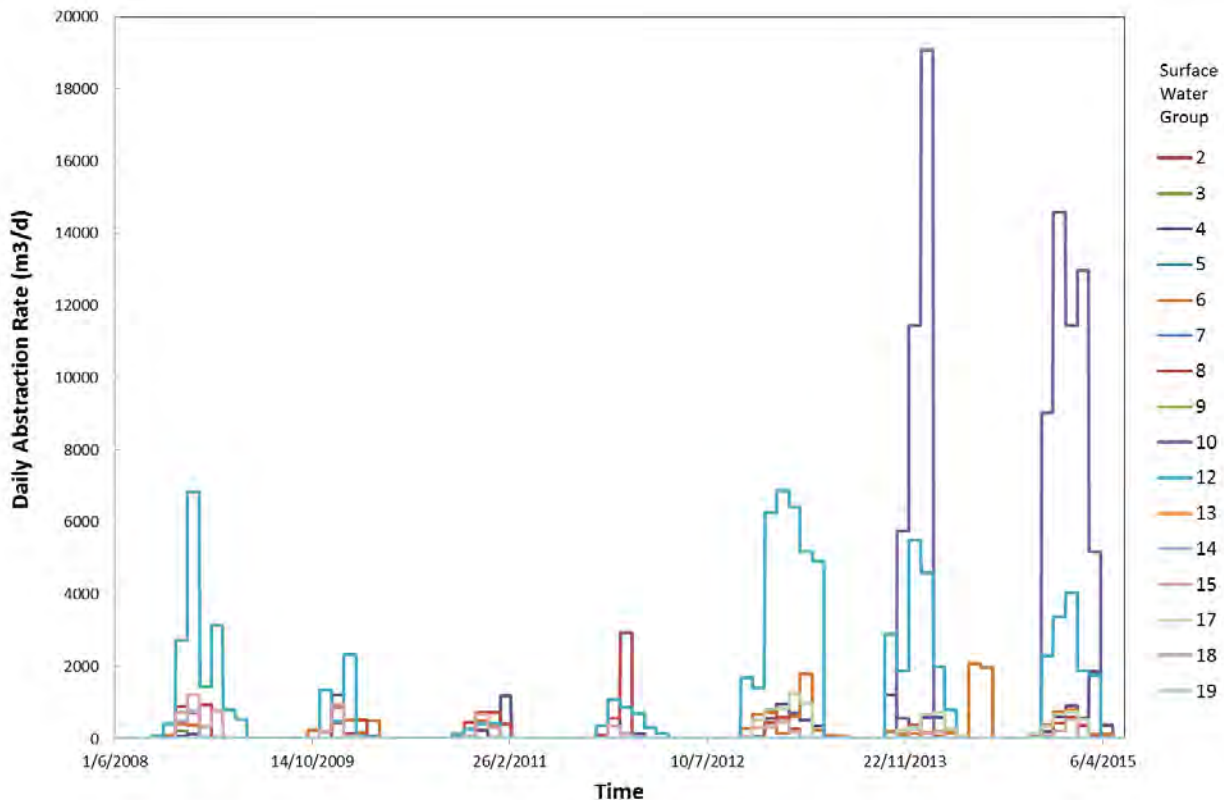


Figure 3.1 : Daily abstraction rate (m³/d) from consented agglomerated water takes grouped into sub catchments. Note: Surface Water Groups are identified in Figure A3, Appendix A.

3.4.2 Irrigation Modelling and Assumptions

Irrigation modelling in the Source model is simplistic in its current approach. The water that has been abstracted was assumed to have been irrigated efficiently and does not contribute return flow recharge of the unconfined aquifer store. A feedback loop can be integrated in future modelling enhancements.

The irrigated component is reflected in the nutrient concentrations through a higher leaching concentration defined based on literature data for FU's which are classified as being irrigated.

Future modelling could include enhancements to the current irrigation module in the Source SMWBM model.

3.5 Hydrology

3.5.1 Gauging Sites

There are numerous river flow monitoring sites through the Waipaoa and Taruheru Catchments (see Table 2.1 for more detail). The primary focus for this Source model has been on calibration and validation to the most downstream gauge at Matawhero. The calibration has then been compared successively upstream against Kanakanaia, Mahaki and Omapere Stations to ensure the flow model is within satisfactory calibration criteria.

These gauging sites are identified in Figure A1 in Appendix A.

3.5.2 Rainfall Runoff Modelling

Source has a number of in-built rainfall runoff models that can be chosen by the user. The Soil Moisture Water Balance Model (SMWBM) was utilised in this situation.

Key parameters of the SMWBM that were calibrated include:

- ST: Soil moisture storage capacity (mm), which is one of the driving parameters influencing the soil water store and regulation of a rainfall event. The higher the ST value, the larger the baseflow contribution will be.
- ZMAX: Maximum infiltration rate of the soil, which used in conjunction with ZMIN determine the actual infiltration rate for each FU, feeding into the soil moisture store (ST). Excess water unable to infiltrate contributes to quickflow.
- FT: Percolation rate from the soil moisture store at full capacity, which effectively drains to underlying aquifers (mm/d).
- GL: Groundwater recession lag (days).
- PI: Interception storage capacity (mm), representing water held in vegetation canopy. This was fixed at 4 mm for forest, and 2 mm for all other FU's.

Three other parameters were fixed in the modelling to reduce the number of metaparameters (and reduce parameter uncertainty), iterations and shuffles as required for the Shuffle Complex Evolution (SCE) procedure. These were:

- ZMIN: Minimum soil infiltration rate used in conjunction with ZMAX. This ranged from 0.2–2.5 mm/hr for different soil drainage types.
- POW: Power of the soil moisture percolation equation, which determines the rate at which soil percolation increases as the ST store increases (and vice versa). During initial calibration runs, POW was determined to be less sensitive parameter to changes in flow and was fixed at 1.7.
- TL: Surface runoff lag (days), which was fixed as 1 day due to the catchment area, average link length and time of concentration calculations.

3.5.3 Stream Reaches

Reaches were modelled as straight through routing, which transfers all generated flow immediately at the end of each timestep (day) with zero storage. Model reaches are presented in Figure A1 in Appendix A.

3.5.4 Calibration Approach

Calibration was undertaken in Source using the automated calibration tool. The calibration approach applied a minimum and maximum range to all the metaparameters (grouped rainfall-runoff parameters per functional unit type) of which a Shuffled Complex Evolution (SCE) global optimiser was then run.

SCE is an efficient global optimiser that is commonly used for many models, including rainfall runoff models. SCE is designed to optimise the metaparameters to increase the fit between simulated and observed flow data. Parameters of the SCE algorithm control the process of optimisation, further detail of which can be found in Duan *et al.* (1992).

Calibration for the Matawhero Station was based on the daily flow record through 1980–2000. Given the number of metaparameters, some calibrations resulted in over 2000 iterations. Each iteration represents one simulation of the 20 year period where an objective function is evaluated based on simulated versus observed results.

The objective function chosen was an equal weighted (50/50) Nash Sutcliffe Efficiency (NSE) for daily flow (m^3/s) and the corresponding log flow duration curve (FDC). NSE & Log FDC is used to assess the predictive power of a hydrological model where a value of 1 indicates a perfect match between observed and modelled

discharge, where a value of 0 indicates the model predictions are only as accurate as the mean of the observed data.

Percent bias (PBIAS), which measures the average tendency of the simulated data to be larger/smaller than observed counterparts, was also used to evaluate model performance.

The combined NSE and PBIAS were used to guide calibration optimisations, which were refined numerous times, changing minimum and maximum ranges, fixing SMWBM parameters such as POW, PI and optimising further through a local optimiser known as Rosenbrook.

Moriasi *et al.* (2007) provides a guideline for watershed simulations to determine satisfactory criteria for NSE and PBIAS in both flow and water quality modelling. This is presented in Table 3.6. Moriasi *et al.* (2007) suggests that streamflow model simulations are deemed satisfactory if the NSE statistic is greater than 0.6 and percent bias is $\pm 25\%$.

Table 3.6 : Performance ratings recommended statistics for a monthly time step (Moriasi *et al.* 2007).

Performance Rating	RSR	NSE	PBIAS (%)		
			Streamflow	Sediment	N, P
Very good	$0.00 \leq \text{RSR} \leq 0.50$	$0.75 < \text{NSE} \leq 1.00$	$\text{PBIAS} < \pm 10$	$\text{PBIAS} < \pm 15$	$\text{PBIAS} < \pm 25$
Good	$0.50 < \text{RSR} \leq 0.60$	$0.65 < \text{NSE} \leq 0.75$	$\pm 10 \leq \text{PBIAS} < \pm 15$	$\pm 15 \leq \text{PBIAS} < \pm 30$	$\pm 25 \leq \text{PBIAS} < \pm 40$
Satisfactory	$0.60 < \text{RSR} \leq 0.70$	$0.50 < \text{NSE} \leq 0.65$	$\pm 15 \leq \text{PBIAS} < \pm 25$	$\pm 30 \leq \text{PBIAS} < \pm 55$	$\pm 40 \leq \text{PBIAS} < \pm 70$
Unsatisfactory	$\text{RSR} > 0.70$	$\text{NSE} \leq 0.50$	$\text{PBIAS} \geq \pm 25$	$\text{PBIAS} \geq \pm 55$	$\text{PBIAS} \geq \pm 70$

3.5.5 Calibration Results

The calibration outputs for the flow model at Matawhero, Kanakanaia and Mahaki Gauges are outlined in Table 3.7. See the subcatchment and flow monitoring sites in the Figure A1 in Appendix A. Calibration of SMWBM parameters for the most downstream gauge (Matawhero), were regionalised to other flow gauging sites and compared to the corresponding flow record.

Table 3.7 : Calibration results and NSE/PBIAS outcomes

Description	Matawhero	Kanakanaia	Mahaki
NSE	0.73	0.79	0.61
PBias error (OBS - MODEL Flow)	-5%	18%	24%
Fit Category (Moriasi <i>et al.</i> 2007)	Very Good	Good	Satisfactory
Comments	Primary calibration gauge	Higher Bias in flows U/S for low/medium flows	Higher Bias in flows U/S for low/medium flows

Figure 3.2 to Figure 3.4 show the simulated versus observed flow calibration results for Matawhero and Kanakanaia Gauges. As outlined in Table 3.7, Kanakanaia and Mahaki (U/S gauges) have simulated flows higher than the observed flow as a consequence of calibrating to Matawhero.

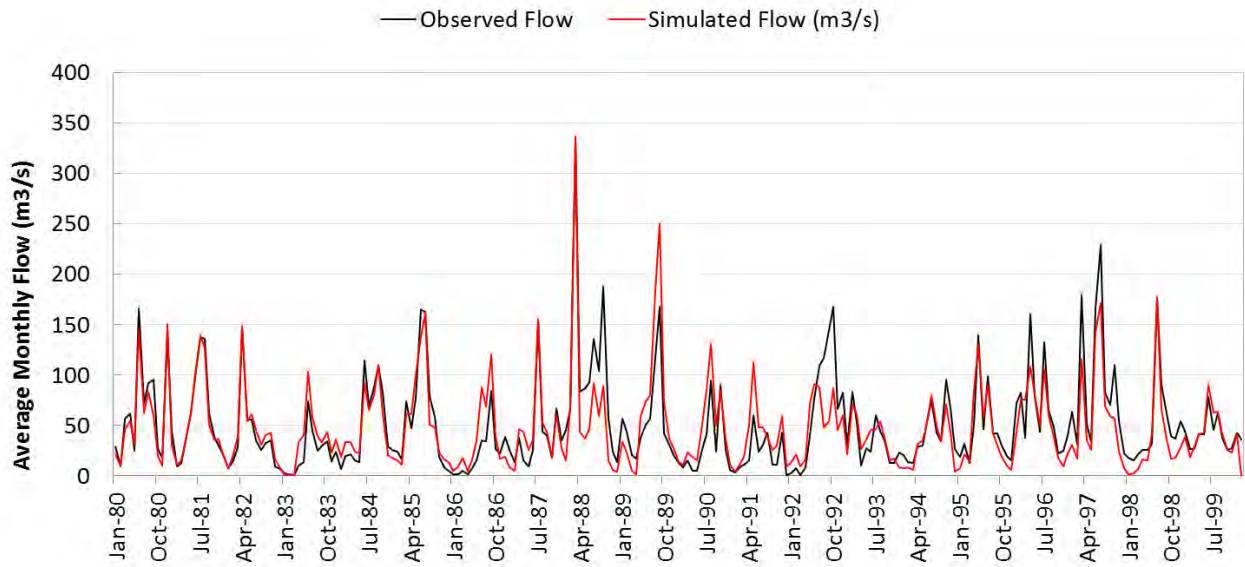


Figure 3.2 : Simulated versus observed monthly average flows for Matawhero Gauge over the calibration period

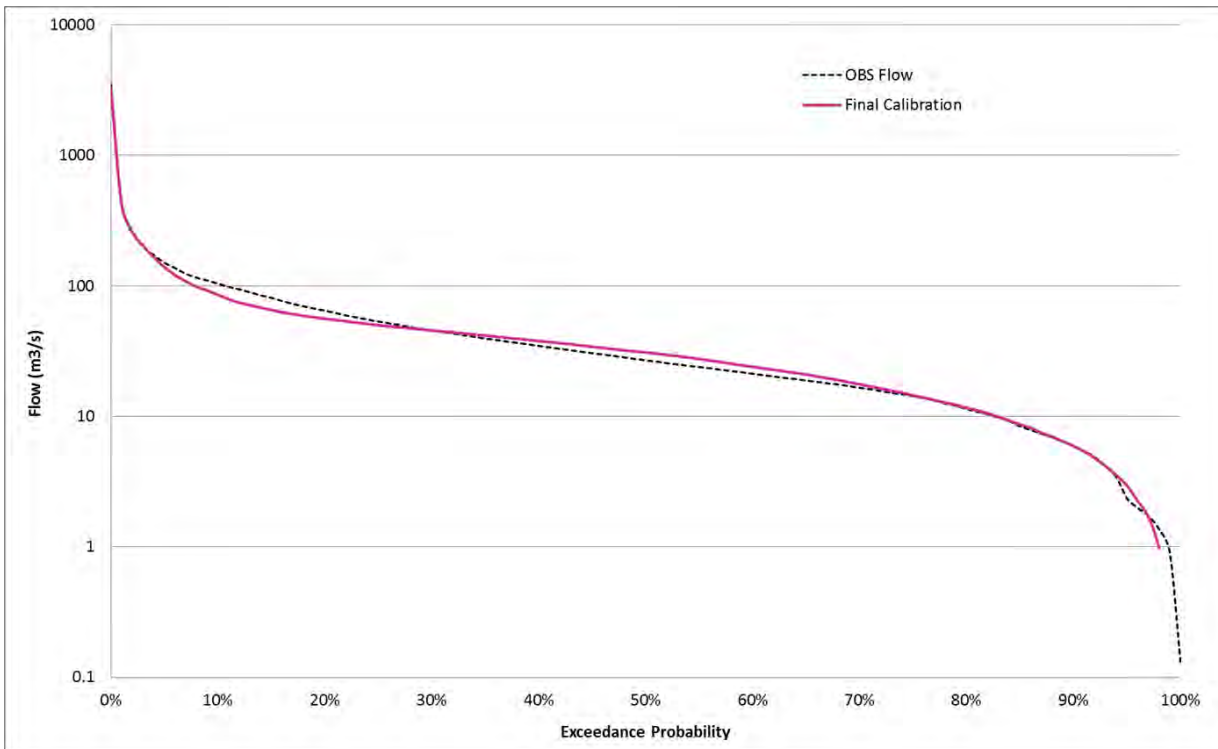


Figure 3.3 : Flow Duration Curve for Matawhero Calibration (1980-2000).

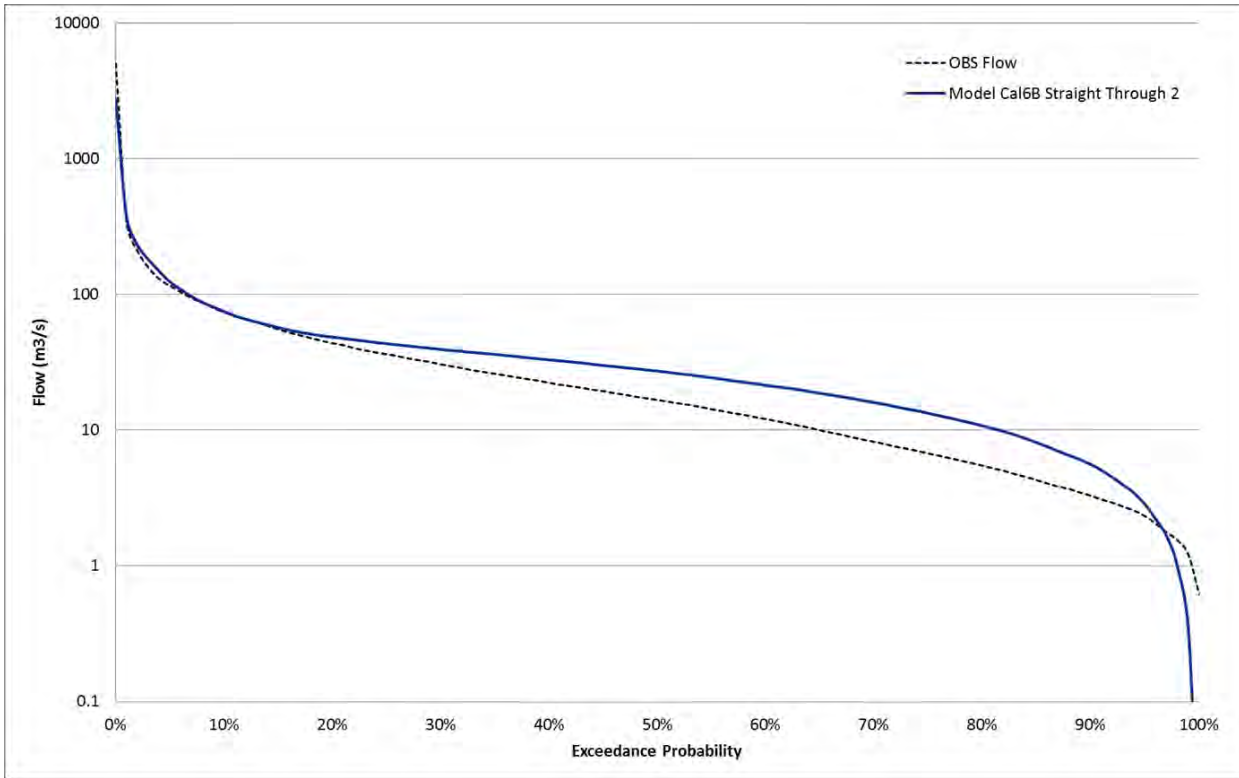


Figure 3.4 : Flow Duration Curve for Kanakanaia Calibration (1980-2000).

3.5.6 Validation Results

The flow model was validated for a 14 year period (2000-2014) at Matawhero Gauge (Figure 3.5). An NSE of 0.65 was achieved for this validation with a PBIAS of 31%. Based on Moriasi *et al.* (2007), this puts the model in a good evaluation criteria range for streamflow (relating to NSE), however an unsatisfactory category relating to PBIAS. The primary reason for the high PBIAS is an overestimation of low to moderate flows.

The model was calibrated to Matawhero and there appears to be some discrepancies between calibration and validation at this gauging site and the sites upstream. Review of the Matawhero FDC's and river flow indicate there has been a potential shift in the flow regime that warrants further investigation.

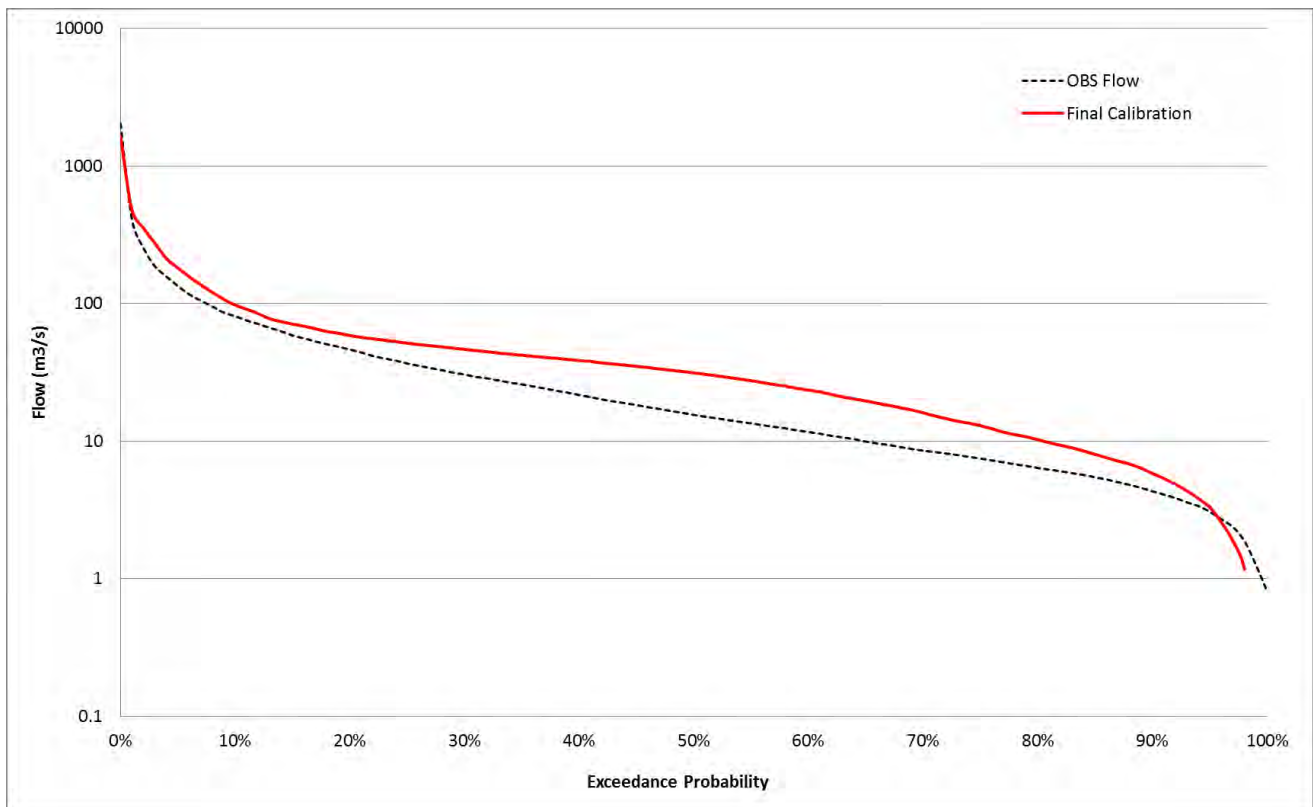


Figure 3.5 : Flow Duration Curve for Matawhero Gauge over the validation period (2000–2014)

Figure 3.3 and Figure 3.4 show there is some difference in simulating low flows between Kanakanaia and Matawhero through the calibration period. Additionally, Figure 3.5 also indicates the calibration fit at Matawhero does not validate well for low-moderate flows through the years 2000-2014. These simulations indicate that the baseflow is being overrepresented in the current model.

There are a number of possible reasons for this, including:

- Oversimplification of groundwater interactions and groundwater abstraction in the model, and
- Higher surface water abstraction upstream of Kanakanaia, greater than what has been extrapolated pre 2008, as outlined in section 3.4.1.

3.6 Water Quality

3.6.1 Total Suspended Solids

TSS data was provided for a number of monitoring sites, of which when plotted against flow allowed the development of rating curves for the Waipaoa and Taruheru Catchments. A rating curve master excel document was provided by GDC and was used as the initial basis to begin evaluating TSS versus flow.

TSS was incorporated into the model as an Event Mean Concentration (EMC) and Dry Weather Concentration (DWC) defined by two key components:

- Landuse Grouping
- Slope Classes

The landuse grouping agglomerated the FU's into 4 main groups, Sheep & Beef, Forestry, Crops and Urban. Following grouping of the landuses per sub-catchment, a slope assessment was undertaken. This split each catchment into three slope categories (low, moderate and steep) as defined in the International Erosion Control Guidelines (2008), outlined in Table 3.8.

Table 3.8 : IECA (2008) Slope Categories

Slope ratio	% grade	Degrees	Classification
<1:10	10%	<5.7	Low
1:4 to 1:10	10-25%	5.7-14	Moderate
>1:4	>25%	>14	Steep

This provided 24 combinations of TSS input concentrations for each of the slope and landuse classifications (12 each for EMC and DWC's). A flow weighted assessment of TSS versus Catchments with predominant landuse types was undertaken to provide initial starting points for potential EMC/DWC values of each of the combinations. This was also coupled with literature reviews around loads generated from cropping and urban areas.

Calibration was initially undertaken by running the model and exporting simulated flow and TSS concentrations at three main gauging's sites (U/S to D/S). The data was then generated into a rating curve and plotted against the stations observed rating curve. Additionally, 1:1 plots of observed versus modelled TSS and their R2 relationship were examined to help make informed decisions about required changes to landuse/slope types.

However following this process of calibration and additional quality control checks, data issues were identified in the excel sediment rating curves and in the Hilltop TSS data. Further correspondence with GDC indicates that TSS data from both these sources is currently unreliable and needs a full audit. For this reason, work on incorporating the TSS model and calibrating this to various stations was ceased.

3.6.2 Nutrients

The primary nutrients modelled were Ammonia-N ($\text{NH}_3\text{-N}$), Nitrate-N ($\text{NO}_3\text{-N}$) and Dissolved Reactive Phosphorus (DRP). Total Phosphorus, Total Nitrogen and Dissolved Inorganic Nitrogen (DIN) were not modelled due to insufficient data in both the P & F report and baseline monitoring.

Nutrients were modelled with an Event Mean Concentration (EMC) and Dry Weather Concentration (DWC) approach, where an EMC is multiplied by the surface flows (quickflow) and the DWC (assumed a leaching rate) is multiplied by the baseflow (slowflow) generated by the SMWBM model to give the total concentration (and total load) generated from the catchments and transported through the river network.

3.6.3 Estimating EMC/DWC

The following approach was undertaken for each of the respective nutrient types:

- **NH₃-N:** DWC and EMC leaching rates were derived off published literature values (see Table C.3 in Appendix C) for Total Nitrogen (for various landuses).
 - From limited observed TN versus $\text{NH}_3\text{-N}$ for the Waipaoa Catchment (<6 samples), a value of ~3% was determined and applied to literature TN concentrations.
 - An attenuation factor of 60% was applied to $\text{NH}_3\text{-N}$ DWC's, consistent with the higher end of nitrogen attenuation literature ranges (see Table C.1 and Table C.2 in Appendix C) from 20-74%.
- **DRP:** Observed field data was used to populate the DWC Concentrations for the model given lack of published information for Waipaoa. EMC's were based on the limited TP data (<4 samples from 4 locations), from P & F report and literature (see Table C.3 in Appendix C).
 - The ratio between TP and DRP averaged ~25% in the wider Waipaoa Catchment and was applied to literature values (i.e. P & F report) to model DRP.

- An attenuation factor of 60% was applied to DRP EMC's, to represent riparian and instream removal of phosphorus, consistent with literature ranges from 40-70%. See Table C.2 in Appendix C.
- **NO₃-N:** NO₃-N makes up 99% of Nitrate-N Nitrite (NNN) load in Waipaoa, so was chosen to be modelled in place of NNN. This was also consistent with the P & F report Nitrate-N modelling.
 - P & F values with average annual drainage based off Matawhero Rainfall were used to derive various cropping and pasture leaching rates. The P & F report resulted in DWC leaching concentrations higher than event (EMC) concentrations.
 - Literature leaching data (see Table C.3 in Appendix C) was used for Sheep and Beef landuses, initially converted to concentrations from drainage rates documented in the P & F report. However this resulted in significantly overestimated the NO₃-N concentrations for the upper catchments. To resolve this issue, upper catchment annual rainfall was used to derive drainage rates (proportioned from total rainfall based on P & F SPASMO outputs) to defined the DWC concentrations
 - Loading from Sheep and Beef catchments was the primary mechanism influencing NO₃-N concentrations.
 - NO₃-N in the Waipaoa is highly seasonal. Concentrations can decrease to ~0.002 mg/L over the dry season, with the large variation in concentrations occurring over the wet season. Characterisation of this was difficult, and resulted in the adoption of the observed DWC concentrations for the sheep and beef landuses in the upper subcatchment (i.e. Mahaki Station) in the model.
 - EMC's were calibrated to match peaks in the observed data.
 - Regardless of these efforts, the model still required an attenuation factor of 90% applied to Nitrate-N to achieve a reasonable calibration. This could be related to deep groundwater interactions, inaccuracies in surface flow volumes or attenuation dynamics currently unknown. This is further outlined in the model limitations (section 3.7).

Input concentrations for EMC and DWC's are presented in Table B.2, Appendix B.

3.6.4 Rainfall and Drainage Rates

Well represented drainage rates are important for determining suitable DWC for nutrients from leaching rate information. Use of the P & F report drainages was found to be too low in the upper catchments, due to the higher annual rainfall (orographic effects). Drainage rates in mm/year are used to convert leaching rates in kg/ha/yr to an input concentration. A higher drainage rate consequently leads to a lower leaching concentration (when converting from kg/ha/yr to mg/L).

The upper catchment annual rainfall rate was determined by assessing the gridded climate data in the model (from 1972-2014) for each of the various upper catchment stations. Annual average rainfall was determined for every subcatchment, with the three catchments closest to each station then used to define that stations range in rainfall characteristics.

Four stations (Te Arai Pykes Weir, Mahaki, Omapere and Waipaoa Station) were then grouped and assessed to determine the average and median annual rainfall depth for the 'upper catchment'. The result was an average annual rainfall of 1754 mm/year and a median of 1794 mm/year, of which the median was adopted. See Table 3.9 for further information.

The P & F report was based on Matawhero Rainfall (average annual ~1060 mm), which was applied to cropping leaching data.

Table 3.9 : Stations and approximate average annual and median rainfall depths

Station Name	Average Annual (mm)	Median Annual (mm)
Waipaoa Catchment (entire)	1353	1240
Matawhero	1059	1067
Kankanaia	1150	1104

Station Name	Average Annual (mm)	Median Annual (mm)
Rangimoe	1370	1370
Te Arai Pykes Weir	1850	1850
Mahaki	1555	1687
Omapere	1774	1774
Waipaoa Station	1838	1808

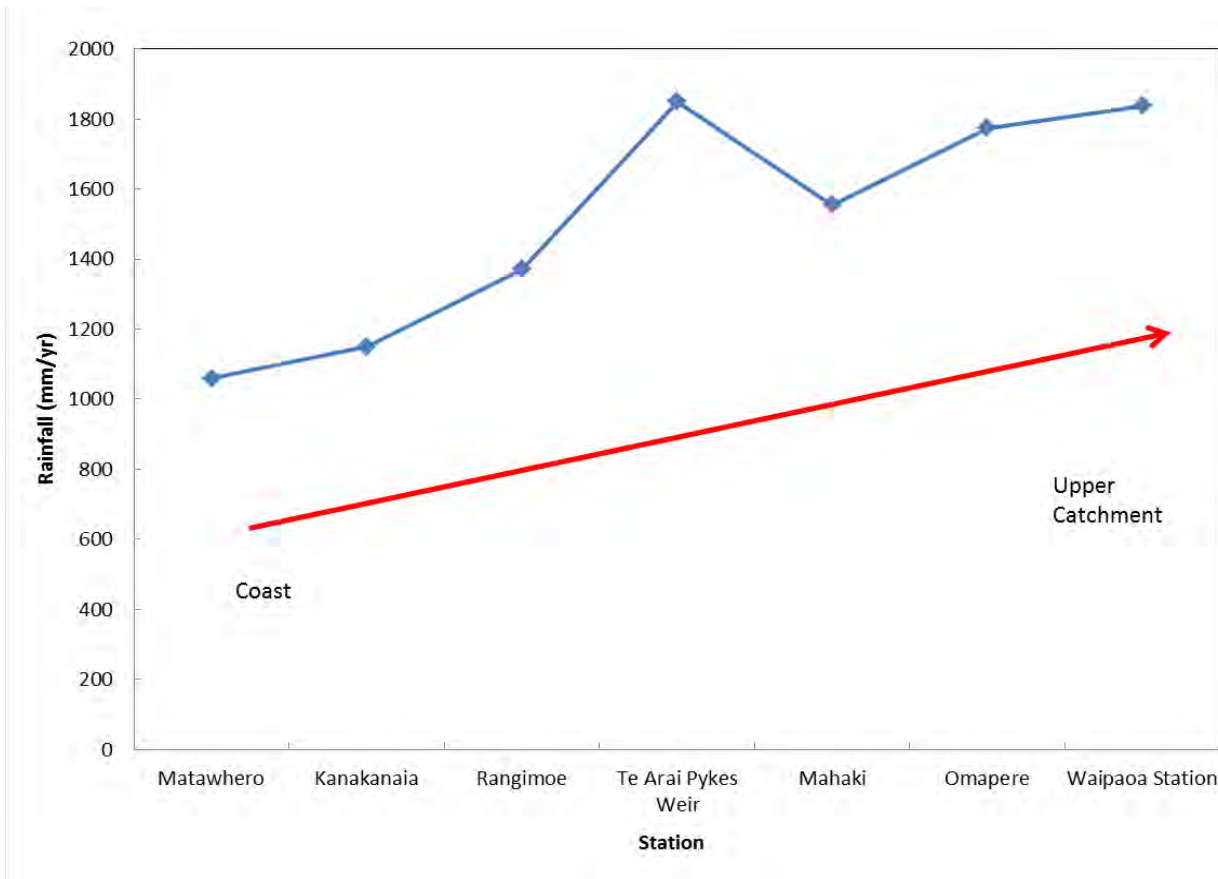


Figure 3.6 : Change in annual average rainfall at different stations

Average annual drainage from the P & F report was ~212.5 mm/yr. Runoff was ~125 mm/yr. These drainage and runoff rates were applied to Nitrate-N, Ammonia-N and DRP to determine input concentrations for cropping landuse layers.

Upper catchments were primarily well drained soils, so the ratio of drainage to total rainfall for well drained soils in the P & F SPASMO modelling was applied in the upper catchment to median rainfall. This was used to help define starting input concentrations for water quality modelling.

3.6.5 Urban Water Quality and Point Sources

Little information was available for point Source inputs and specifically for urban water quality. Estimates have been made for nutrient inputs from these locations, but further work is required.

3.6.6 Calibration

Calibration simulations were undertaken for water quality to define input EMC/DWC parameters from various landuse and soil drainage types. Daily data was aggregated into monthly flow weighted concentrations and compared against observed monthly water quality data for the period from 2003-2014.

Due to the variable nature of water quality data, the PBIAS metric has been used as an indicator for model fit (Table 3.10), with box plots created to compare median and upper/lower quartiles. These are considered a good/very good fit when compared to Table 3.6.

Table 3.10 : PBIAS (observed versus simulated concentrations) in final water quality model calibration

Sites	NO ₃ -N	NH ₃ -N	DRP
Mahaki	-13%	19%	12%
Kanakanaia	-2%	15%	-1%
Matawhero	-8%	-15%	0%

Note that a low PBIAS may not always capture the full range in peaks and troughs in observed data, but represents the median/average well. This requires subjective analysis on behalf of the modeller, and for the case of Waipaoa River, further work is required to simulate peaks in nutrient concentrations.

Higher variability in PBIAS (Table 3.10) is observed in NH₃-N, with the lowest variability observed in DRP at the three sites. A positive PBIAS indicates simulated concentrations are higher than observed, negative meaning simulation concentrations are lower. Interestingly, NH₃-N has higher than observed median concentrations in the upper catchment but underestimates NH₃-N downstream at Matawhero. This requires further investigation and may indicate that the upper landuse nutrient inputs for sheep and beef may be too high (or drainage rates not representative of what is actually occurring), or the lowland cropping inputs are currently too low for Ammoniacal N (which could be why simulated median concentrations are underestimated at Matawhero).

Box plots for Matawhero are presented in Figure 3.7 and Figure 3.8, which shows the difference between the variation in observed and simulated water quality concentrations. Simulated median NO₃-N represents observed median concentrations well; however the model under predicts the large variability in the observed data. The model would benefit from further data collection and model refinements related to groundwater interaction and seasonality in Nitrate-N loads.

Ammoniacal-N and DRP generally have a smaller concentration range in the observed upper to lower quartile results when compared to NO₃-N (Figure 3.7). The baseline calibration results sit within these observed ranges, although the median simulated concentration for DRP is slightly higher than observed.

For all nutrients, the model had a better calibration for median concentrations, rather than high and low confidence intervals (5th and 95th percentiles). Further calibration is necessary to capture the peaks and troughs. Reporting on these outer values should be used with caution. However the model will be suitable to provide an indication of the % change that may occur with the median values in the scenario analysis. For this reason, median results have been presented when looking at the scenario analysis in section 4.

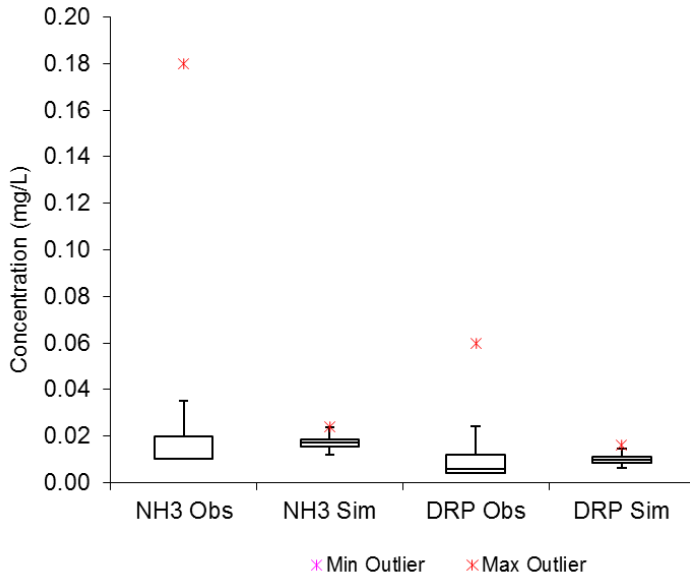


Figure 3.7 : Matawhero NH₃-N and DRP Calibration Box Plots (min, max, LQ, UQ, Median and outliers)

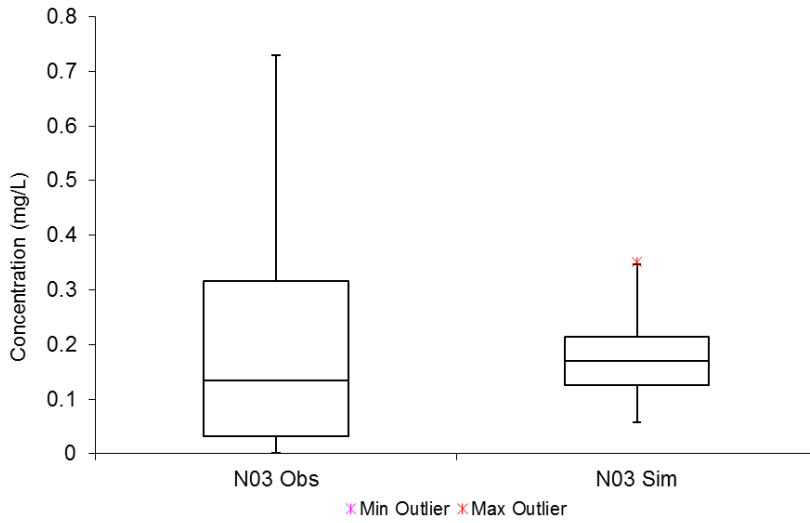


Figure 3.8 : Matawhero NO₃ Calibration Box Plots (min, max, LQ, UQ, Median and outliers)

3.7 Assumptions and Limitations

The assumptions and limitations of the model are listed below, and provide an understanding of where refinements can be made in the future.

3.7.1 Hydrology/Hydrogeology

Source catchment modelling has some of the following considerations

- S-Map soil drainage layers have been refined to 2 drainages types, poor and well drained. All imperfect to very well drained soils have been merged as one layer, while poor/very poor represent the other.
 - These result in a significant proportion of the Waipaoa Catchment being considered well drained (~95%).
- River reaches have been considered as straight through routing, with no hydraulic functionality (instantaneous) and no storage.
- There are 12 landuse types, 2 soil drainage types and an irrigated or non-irrigated integration to create 39 functional units (FU's) across the entire catchments.
 - Flow calibration has grouped these 39 FU's into 4 groups, defined as Crops, Forestry, Sheep/Beef/Pasture and Urban. These 4 groups are grouped with the same rainfall runoff parameters during calibration to avoid overparameterisation and parameter uncertainty.
 - The large number of FU's was mainly to facilitate scenario modelling, but can allow future revisions to focus on enhancing flow and nutrient loading calibration at more specific landuse and soil drainages.
- Abstracted water based on actual consent data (primarily for irrigation) is removed from the system as a daily time-series at 16 locations along the two rivers.
 - >90 surface water consents were grouped to reduce nodes required in the model, with one abstraction time series applied per specific link/catchment locality.
 - Irrigated landuses have been assumed to efficiently use all water, with return flow of irrigated water to the river.
- There are no groundwater consented takes incorporated in modelling and no groundwater modelling component besides a simple groundwater store to derive baseflow contributions as an output from the rainfall runoff modelling.
 - Flow calibration would however take into account the historical effects of any groundwater takes if they resulted in stream depletion.
- Calibration was undertaken for Matawhero Gauge. The period was 20 years, with a validation of 14 years. Acceptable calibration at this gauge was compared to other U/S gauges to ensure they were within satisfactory criteria. The model was not explicitly calibrated from U/S gauges to D/S gauges. This is considered to be a further component to model enhancement.

3.7.2 Water Quality

The water quality (WQ) modelling process has focussed on an Event Mean Concentration (EMC) and Dry Weather Concentration (DWC) approach, further described in section 3.6. Nutrient modelling is inherently variable, with the focus on characterising first the annual median concentrations and load, and secondly on

matching peaks and troughs. Calibration was based on the continuous period of monthly WQ sampling from 2003-2014.

The model had a better calibration for median concentrations, rather than high and low (5th and 95th percentiles). Further calibration is necessary to capture the peaks and troughs, and reporting on these values should be used with caution.

- Modelling focussed on Nitrate-N ($\text{NO}_3\text{-N}$), Dissolved Reactive Phosphorus (DRP), Ammonia ($\text{NH}_3\text{-N}$) and TSS. Nitrate represented ~99% of NNN load (Nitrate-N+Nitrite) in most catchments and was modelled in the P & F report, so was chosen to be modelled rather than NNN.
- Flow data versus water quality spot samples from monitoring sites were analysed to determine EMC's and DWC's. EMC's were determined to be any nutrient concentrations where flow was >70th percentile of the daily records for that site. DWC's were derived off the inverse of these flows.
 - The final EMC or DWC for each site was derived by a flow weighted assessment of the sum product of flow versus filtered nutrient concentrations.
- Water quality data was available for some sites dates back as far as 1978. However initial assessments of this data indicated large discrepancies between the more recent records from 2003, resulting in outliers and skewing of the EMC and DWC results. Therefore, this data was removed with the focus on WQ from 2003-2014.
- DWC and EMC derived from observed in-stream data were used where literature data or modelling data (i.e. P & F report) was unavailable. This was undertaken for DRP and $\text{NO}_3\text{-N}$.
- Limited Total Nitrogen (TN) and Total Phosphorus (TP) data was available for all monitoring sites, which made determining speciation difficult.
- There was limited information in the P & F report (Gentile et al. 2014) for cropping landuses on $\text{NH}_3\text{-N}$, TSS and DRP. Their focus was on TP and NO_3 on an annual basis.
- TP versus DRP in Waipaoa indicated an average ratio of ~25%. This was applied to P & F report and literature TP data.
- TN versus $\text{NH}_3\text{-N}$ observed data indicated ammonia is in low concentrations, with an average ratio of ~3%. This was applied to literature TN data to derive $\text{NH}_3\text{-N}$ EMC's and DWC's.
- P & F cropping loads were based off annual average rainfall for Matawhero, which is ~1030 mm/year. The drainage rates/proportions derived off SPASMO modelling were applied to literature loading values to determine concentrations
 - However this resulted in high concentrations in the upland catchments, which consequently receive much greater annual rainfall (median value of ~1,800 mm/year near Mahaki Station).
 - Consequently, drainage rates were revised to represent proportionate drainage from well drained soils with a higher annual rainfall. This was applied to nutrient loads (i.e. kg/ha/yr) for various landuse types (i.e. Sheep, Forestry, Beef) to refine EMC and DWC concentrations.
- Attenuation factors of 60% were applied to $\text{NH}_3\text{-N}$ and DRP, while a factor of 90% was applied to NO_3 .
 - $\text{NH}_3\text{-N}$ and DRP attenuation fall within literature values for in stream and riparian attenuation (although on the higher end).
- NO_3 attenuation was high, above typical literature values from 30–70%. Possible reasons for this include:

- Flow Modelling: The Matawhero and Kanakanaia Gauges appear to have a noticeable change in their FDC from around 1997 onwards.
 - This results in the model overestimating baseflow through the validation period, which consequently would overestimate loads (particularly for NO₃).
 - The change in flow could be attributed to increased abstraction, which may be linked to groundwater connectivity/pumping, resulting in a lower observed baseflow than through the 20 year calibration period.
 - This requires further evaluation, or even re-calibration in the future with a focus on the last 15 years.
 - A baseflow study should be undertaken for different periods.
- Groundwater Model: The current model is a Surface Water model with a limited groundwater component.
 - There is a good possibility that some of the Nitrate-N attenuation over the dry season maybe due to deep groundwater flows which are not observed in the river measurements.
 - Linking this surface model with a groundwater model (Phase II) will help evaluate this further, and may improve the baseflow representation.
- Nitrate-N Seasonality and Attenuation: Little data is available on NNitrate-N seasonality and attenuation in the Waipaoa, particularly in the upper catchment. Seasonal trends are obvious, with very low concentrations exhibited during summer periods, and flushes occurring over winter.
- Further research into this area (possibly in conjunction with groundwater recharge) may resolve some questions.

4. Model Results

4.1 Baseline flow results

Section 3.5 and 3.6 provided an overview of the baseline model calibration and validation results. The baseline model water quality results are outlined further in the Scenario Trials described below and in Appendix E.

The following results present the mean daily flow and mean annual seven day low flow for a variety of gauging sites.

Table 4.1 : Baseline Model Flow Statistics (simulated)

Name of Node	Mean Daily Flow (m ³ /s)	Mean Annual 7 day Low Flow (m ³ /s)
Brunton Road Gauge	1.77	0.05
Kaiteratahi Bridge Gauge	45.99	2.98
Kanakanaia Gauge	43.42	2.90
Mahaki Gauge	4.40	0.38
Matawhero Gauge	49.52	3.08
Omapere Station Gauge	6.50	0.51
Rangimoe Gauge	3.36	0.25
Te Arai River at Pykes Weir	3.19	0.16
Terrace Station Gauge	6.05	0.28
Tuckers Road Gauge Taruheru	0.74	0.01
Waipaoa Station Gauge	7.40	0.58

4.2 Scenario Trials

Two scenarios were modelled:

- Scenario 1: Additional irrigation development. This scenario would investigate the consequences for an addition area of existing horticulture land to be irrigated. This falls in line with the proposed irrigation area in the Draft Report “The Value of the Horticultural Sector to the Gisborne Economy” by the Agribusiness Group (2016). Nutrients Ammonia-N (NH₃-N), Dissolved Reactive Phosphorus (DRP) and Nitrate-N (NO₃-N) will be compared.
- Scenario 2: A permitted Nitrate-N loss level for productive landuse: This scenario would seek to investigate the introduction of minimum load for flat productive land (<15^o). The focus was on Nitrate-N (NO₃-N), given the model has been calibrated for NO₃-N due to a lack of TN data

4.2.1 Scenario 1

4.2.1.1 Methodology

This scenario followed the approach undertaken in the Agribusiness report which outlined a doubling in irrigation area from ~2600 Ha to ~5200 Ha. Any landuse in the model that was already irrigated was doubled in area proportionately, with the increase in area balanced by removal of the area from non-irrigated landuse of the same type.

Irrigated landuse in Waipaoa has a ~15% increase in concentrations in the Baseline model, as determined from SPASMO modelling in the Plant and Food Report. Consequently this higher leaching rate was applied to the greater area to be irrigated for this scenario.

Additionally, surface water abstractions at the various sites have been doubled to reflect (assumed) greater water use and reduce river volumes. All water applied in the irrigation scenario is assumed to be efficiently used, there is no feedback loop draining this water back into the river. This is a conservative assumption that

reduces the river volume and consequently would lead to higher concentrations (albeit minor due to the small total volumes of abstractions).

Full results for DRP, NH₃-N and 5th, median and 95th percentiles have been reported in Appendix E.

4.2.1.2 Results

The median concentration results are presented for scenario 1 and the baseline model, comparing the % change in concentration as a result of doubling the irrigation area. This is for DRP, NH₃-N and NO₃-N.

Table 4.2 : Scenario 1 Median (50th percentile) Nitrate-N Results

Median	Concentrations (mg/L)		% Increase from baseline
	GDC Plan Limits	Baseline Model	Sc1 - Double Irrigation Area
Wharekopae River Rangimoe	0.08	0.08	-
Whakaahu River Brunton	0.09	0.13	1.3
Waipaoa River at Matawhero Bridge	0.14	0.09	2.4
Waipaoa River at Kanakanaia	0.10	0.08	0.7
Waingaromia River at Terrace St	0.07	0.04	-
Mangatu River at Omapere Station	0.14	0.09	-
Taruheru River at Tuckers Road	0.67	0.44	8.5

Limited change from the baseline was observed in Nitrate-N concentrations, except in Taruheru due to the higher proportion of cropping in this location. The minimal change elsewhere may be impacted by the drainage rate and nutrient inputs assumptions in the model, and also the fact the increased irrigation area only represents a small proportion of the total catchment area (~2.2%).

Table 4.3 : Scenario 1 Median (50th percentile) DRP Results

Median	Concentrations (mg/L)		% Increase from baseline
	GDC Plan Limits	Baseline Model	Sc1 - Double Irrigation Area
Wharekopae River Rangimoe	0.009	0.007	-
Whakaahu River Brunton	0.009	0.008	0.6
Waipaoa River at Matawhero Bridge	0.006	0.008	0.8
Waipaoa River at Kanakanaia	0.005	0.007	0.3
Waingaromia River at Terrace St	0.004	0.006	-
Mangatu River at Omapere Station	0.004	0.008	-
Taruheru River at Tuckers Road	<0.03*	0.013	6.2

* Target median limit

Table 4.4 : Scenario 1 Median (50th percentile) NH₃-N Results

Median	Concentrations (mg/L)		% Increase from baseline
	GDC Plan Limits	Baseline Model	Sc1 - Double Irrigation Area
Wharekopae River Rangimoe	0.010	0.012	-
Whakaahu River Brunton	0.011	0.013	0.3
Waipaoa River at Matawhero Bridge	0.010	0.014	0.5
Waipaoa River at Kanakanaia	0.010	0.014	0.2
Waingaromia River at Terrace St	0.010	0.015	-
Mangatu River at Omapere Station	0.010	0.012	-
Taruheru River at Tuckers Road	0.010	0.020	5.5

Table 4.3 and Table 4.4 show DRP and Ammoniacal-N exhibit only a small increase in concentration in the Waipaoa River sites as a result of doubling in irrigation area. This is most likely due to the Waipaoa River having a large catchment area that is over 90% sheep and beef, with irrigated horticulture area being significantly smaller. While cropping contributes a higher load than sheep and beef, the large low intensity upper catchment landuses and higher river flow may provide some buffering. Additionally, irrigation in the model was represented as a 15% increase to EMC and DWC concentrations as determined from P & F report, however this may be higher of which field measurements could verify.

Given Taruheru catchment has the highest cropping density, the same trend in concentration increase is observed in this location (Tuckers Road), where a doubling in irrigation area results in a 6.2% and 5.5% increase from baseline for DRP and NH₃-N.

Similar trends were observed in the 5th and 95th percentiles for these nutrients, with the greatest increase observed in Taruheru River. As outlined in assumptions and limitations in section 3.7, median results currently provide a better indication of the general trends that may be observed should this scenario occur.

As outlined in section 3.6.6, Table 3.10, PBIAS median NH₃-N concentrations were being underestimated at Matawhero Station (downstream sites). For this reason, the % increase in expressed in NH₃-N (Table 4.4) for Matawhero and Tuckers Road may be slightly underestimated.

4.2.2 Scenario 2

4.2.2.1 Methodology

The productive landuse scenario required a GIS assessment first to determine the productive landuse functional units. An input file to the Source model representing the new functional unit list (FU) including the productive land was created by using a 15m DEM of the Waipaoa catchment area and classifying the area into two slope classes, 0-15 degrees and over 15 degrees.

The 0-15 degree class is considered 'productive land' and was intersected with the existing 39 functional units at a property level. The analysis method resulted in some properties having areas of productive land and areas not considered productive; and in these cases properties with 75% or more of their land in the productive category were assigned to 'productive land'. See Figure A4 in Appendix A.

This primarily resulted in the Waipaoa flats and some of the valleys in the hill country being classed as productive. The data was then exported as an ASCII grid from the Source model with a cell size of 100m. The analysis increased the 39 functional units to 55. The total productive landuse area was 25,506 ha of which baseline cropping FU's made up 12,380 ha.

The refined functional unit list was then matched to calibrated baseline rainfall runoff and water quality parameters. Cropping (maize, vegetables, citrus and grapes) areas were then proportionately increased in size per subcatchment at increments of 25%, 50%, 75% and 100%. A 100% increase in cropping area would result in crops having an area of 24,760 ha or 97% of the productive land use zone.

For each proportionate increase outlined above, non-cropping (yet productive) land was reduced in size by the equivalent amount. This focussed on reducing land use types in the priority order of pasture, sheep and beef then other.

Some lowland catchments had significant proportions of cropping with little room for 50–100% area increases. Their equivalent area increase was re-allocated to other catchments. Generally these were upstream, above the Kanakanaia Gauge. However subjective priority was given to the pasture land use types being converted first, generally through the lowland poverty bay flats transitioning to the upper catchment.

The results were compared against the baseline model to determine the relative change in Nitrate-N concentrations as a function of increased cropping.

The input loading rate in kgN/ha/yr has also been presented. These were derived by back-calculating the input Nitrate-N leaching concentrations from the average annual drainage rate (212.5 mm/yr) out of the P & F report. A conversion factor of 0.5 has been applied, which represents modification of input concentrations from Nitrate-N to total nitrogen, where 4x spot samples in the Waipaoa River at various catchments indicated the average proportion of Nitrate-N in total nitrogen was ~50%.

4.2.2.2 Results

Table 4.5 : Scenario 2 Median (50th percentile) Nitrate-N Results

Median	Concentration (mg/L)		% Increase from baseline at greater intensifications				Comment
	GDC Plan Limits	Baseline Model	25%	50%	75%	100%	
Wharekopae River Rangimoe	0.075	0.08	0.0	0.0	0.0	0.0	No apparent change, most likely as upland catchment with little cropping
Whakaahu River Brunton	0.085	0.13	5.9	12.4	20.2	27.8	Significant increase in concentration, however model is reporting baseline values already higher than Plan Limits. Potential limits due to calibration/validation
Waipaoa River at Matawhero Bridge	0.14	0.09	3.5	9.8	20.4	30.5	Increase in concentration, as expected due to lowland origins and primarily cropping and flatter productive land. Modelled increases are still below WQ limits
Waipaoa River at Kanakanaia	0.102	0.08	1.4	5.7	15.1	24.0	Increase in concentration, as expected due to lowland origins and primarily cropping and flatter productive land. Modelled increases are still below WQ limits
Waingaromia River at Terrace St	0.07	0.04	0.0	0.0	0.0	0.0	No apparent change, most likely as upland catchment primarily forestry
Mangatu River at Omapere Station	0.139	0.09	0.0	0.0	0.0	0.0	No apparent change, most likely as upland catchment with little cropping
Taruheru River at Tuckers Road	0.67	0.44	10.5	24.3	26.4	29.1	Greatest increase in concentration observed in up to 50% change in area, due to the reduced amount of land available to be converted.

Table 4.6 : Input Loading Rates (kgN/ha/yr*) applied in Scenario 2

Productive Landuse	Baseline	Approximate Equivalent Fertilizer Application
Pasture	18	40 kg/ha Urea
Citrus	50	250 kg/ha Nitrophoska Blue, 100 kg/ha CAN
Grapes	11	No fertilizer, baseload leaching off P & F report
Maize	37	200 kg/ha Cropmaster 20
Vegetables	38	300 kg/ha Nitrophoska Blue

*Correction factor of 0.5 applied, as model used TN loadings to model NO₃ of which appears to average ~50% in the observed water quality spot sampling results.

Table 4.5 shows that with an increase in cropping landuse in the productive zone, concentrations consequently increase at a number of sites. Intensive cropping has higher nutrient inputs than some of the existing landuse types that would consequently be converted (i.e. pasture, lowland sheep and beef).

This scenario is catchment area and slope dependent, where once the productive zone area within a catchment has been converted, no further conversions would occur. For some catchments with limited productive area available for conversion, this may mean that the 25% increase in cropping area applied to productive land zones could result in the majority of current landuses converting to cropping within a subcatchment.

5. Summary

This work represents the first phase of development for a functioning catchment model. Over time, further refinements through calibrations and validations, and coupling with a groundwater model will allow representation of the wider hydrological system. This will enable entire catchment wide planning, for both surface and groundwater, and will allow management of both water use and water quality.

The current model draws on the best available data at the time. The model utilises significant GIS layers that provide a spatial overview on the high density poverty bay flats cropping, sheep, beef and forestry through the Agribase layers (including stocking rates) and soil drainages through SMap. This led to the development of 39 functional units representing combinations of landuse type and soil drainages, further refined into areas by 50 subcatchments draining the Waipaoa and Taruheru Rivers.

Calibration and Validation of the flow model was primarily undertaken for one main gauging site, Matawhero, with comparisons made against two upstream sites (Kanakanaia and Mahaki).

While the current model is considered a good to very good fit for NSE (>0.7) for these gauging sites, further refinement will improve the PBIAS for low to moderate flows and allow better representation of the river volumes, which will help in refining the water quality model. Nevertheless, the representation of the catchments hydrology by the model is suitable for investigating the relative change between scenarios for landuse change and water quality impacts.

The water quality model has been calibrated to the same three stations outlined above. The water quality model has a good to very good fit for these stations. The median results are the most applicable for comparing to observed water quality data, while the model currently underestimates the upper and lower concentrations that may occur during discrete rainfall events.

A number of assumptions (primarily based off literature) have been undertaken for the water quality model that will require further research and data collection to verify these input values.

Recommendations are discussed below in Section 6.

6. Recommendations

A baseflow study should be undertaken for a range of periods, to identify any rating curve shifts in the river, and particular timeframes where higher abstraction may be resulting in this change in baseflow. The model could be re-calibrated to capture increased surface water abstraction, or calibrated and validated for a shorter more recent period concurrent with the most relevant water quality data (from 2003 onwards).

Additionally, water level and flow data should continue to be collected for a number of sites, particularly in the Tarueru River. A long term, reliable flow dataset will help in calibrating and validating the flow model at a number of locations.

While the current model is considered a good to very good fit for NSE for these gauging sites, further refinement will help reduce the PBIAS for low to moderate flows and allow better representation of the river volumes, which will help in refining the water quality model. A nested calibration using multiple gauging sites from various locations will also help in refining the flow model.

The water quality model will also benefit from refinement in calibration of input concentrations and attenuation given further site-specific data collection and analysis, which will lead to a more reliable model for forecasting landuse change impacts. Event monitoring of nutrients and sediments to refine EMC parameterisation and calibration, as well as determination of key river reaches where nutrient reduction are likely to occur (through increased denitrification/oxidation) to improve attenuation rates would greatly improve the water quality simulations.

Currently the model does not incorporate TSS. Once data quality checks have been completed, addition of TSS would be beneficial. This could be undertaken in conjunction with further surface water calibrations and baseflow analysis, to ensure simulated flows and volumes accurately represent TSS loads and concentrations. Given the significant sedimentation rates generated within the Waipaoa catchment an alternative modelling approach may be to incorporate the daily SedNet plugin into Source to better represent hillslope and gully erosion processes.

Furthermore, the current water quality data analysed in Gisborne does not account for Total Nitrogen and Total Phosphorus. It is recommended that these are added to the suite of analytes so a better understanding of total versus dissolved loads can be obtained.

Urban water quality is currently a large unknown in the Gisborne area. Significant point sources (such as waste water treatment plants) should be sampled/monitored regularly to build up an understanding of their potential nutrient inputs.

Water quality inputs for a number of landuses have been derived from literature values, modelling or interpolated off observed in stream water quality data. Localised field studies of leaching and runoff concentrations from landuses such as Sheep and Beef, Cropping (i.e. Maize, Citrus, Grapes, Vegetables) and Urban sites would be beneficial to help verify some of the adopted values.

Attenuation factors are currently implemented in the model as a percentage reduction in load. Little information is available on denitrification and attenuation of N and P nutrients in Gisborne. Further studies in this area would be beneficial to help refine the assumed parameters adopted at this current stage. There may be high levels of denitrification, or removal of nutrients through attenuation by mechanisms such as in-stream burial, which needs to be better understood.

Development of a regional 3D groundwater model (such as MODFLOW) would also be very useful for catchment scale planning. This would allow surface and ground water interactions to be modelled concurrently, where in its present state the model has no consented groundwater takes included or deep groundwater contributions being analysed (although these are inherently represented through the surface water calibrations).

There may be some attenuation occurring within the various shallow or deep aquifers in the Waipaoa Catchment, which could be a cause for the higher attenuation factors that had to be applied to Nitrate-N inputs

(up to 90%). Integration of a surface water and groundwater model would allow a robust approach to analyse water abstraction, availability and water quality changes over time. This would provide a sound scientific approach to forecast land use change impacts and allow for sustainable development within the Waipaoa and Taruheru Rivers.

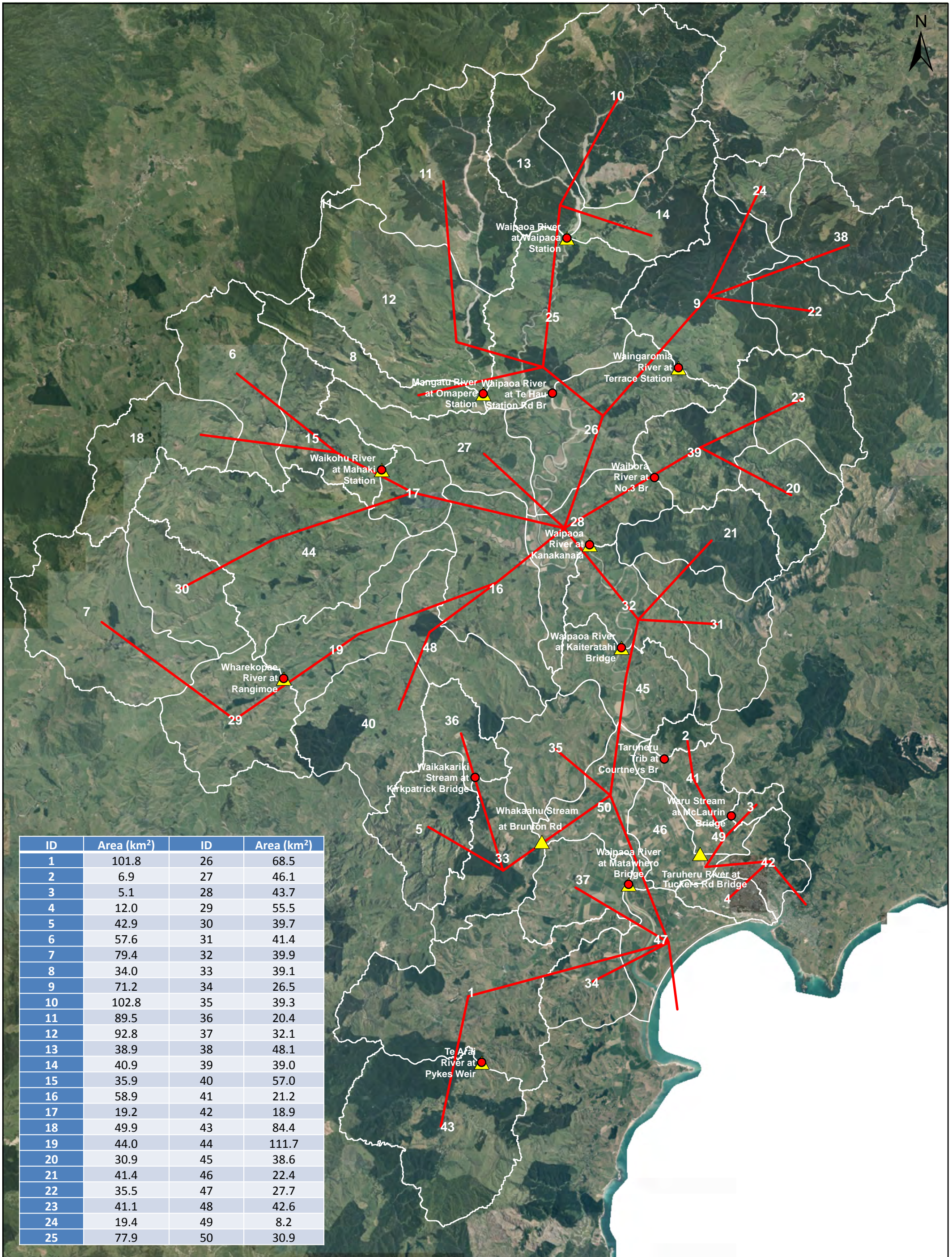
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Appendix A. Figures



ID	Area (km ²)	ID	Area (km ²)
1	101.8	26	68.5
2	6.9	27	46.1
3	5.1	28	43.7
4	12.0	29	55.5
5	42.9	30	39.7
6	57.6	31	41.4
7	79.4	32	39.9
8	34.0	33	39.1
9	71.2	34	26.5
10	102.8	35	39.3
11	89.5	36	20.4
12	92.8	37	32.1
13	38.9	38	48.1
14	40.9	39	39.0
15	35.9	40	57.0
16	58.9	41	21.2
17	19.2	42	18.9
18	49.9	43	84.4
19	44.0	44	111.7
20	30.9	45	38.6
21	41.4	46	22.4
22	35.5	47	27.7
23	41.1	48	42.6
24	19.4	49	8.2
25	77.9	50	30.9

CLIENT
GDC, Hort NZ

PROJECT
Waipaoa Catchment Source Model

SCALE
1:214,649 @ A3

PROJECT CODE
AE04830

PROJECT MANAGER
JB

DRAWN
JB

PROJECT DIRECTOR
XX

DATE
8/07/2016

● Monitoring Sites with Flow Records
 Waipaoa Catchment

▲ Monitoring Sites for Water Quality
 — Network_Links_UTM60

— Flow_Gauge_Catchments_Rev3_JB

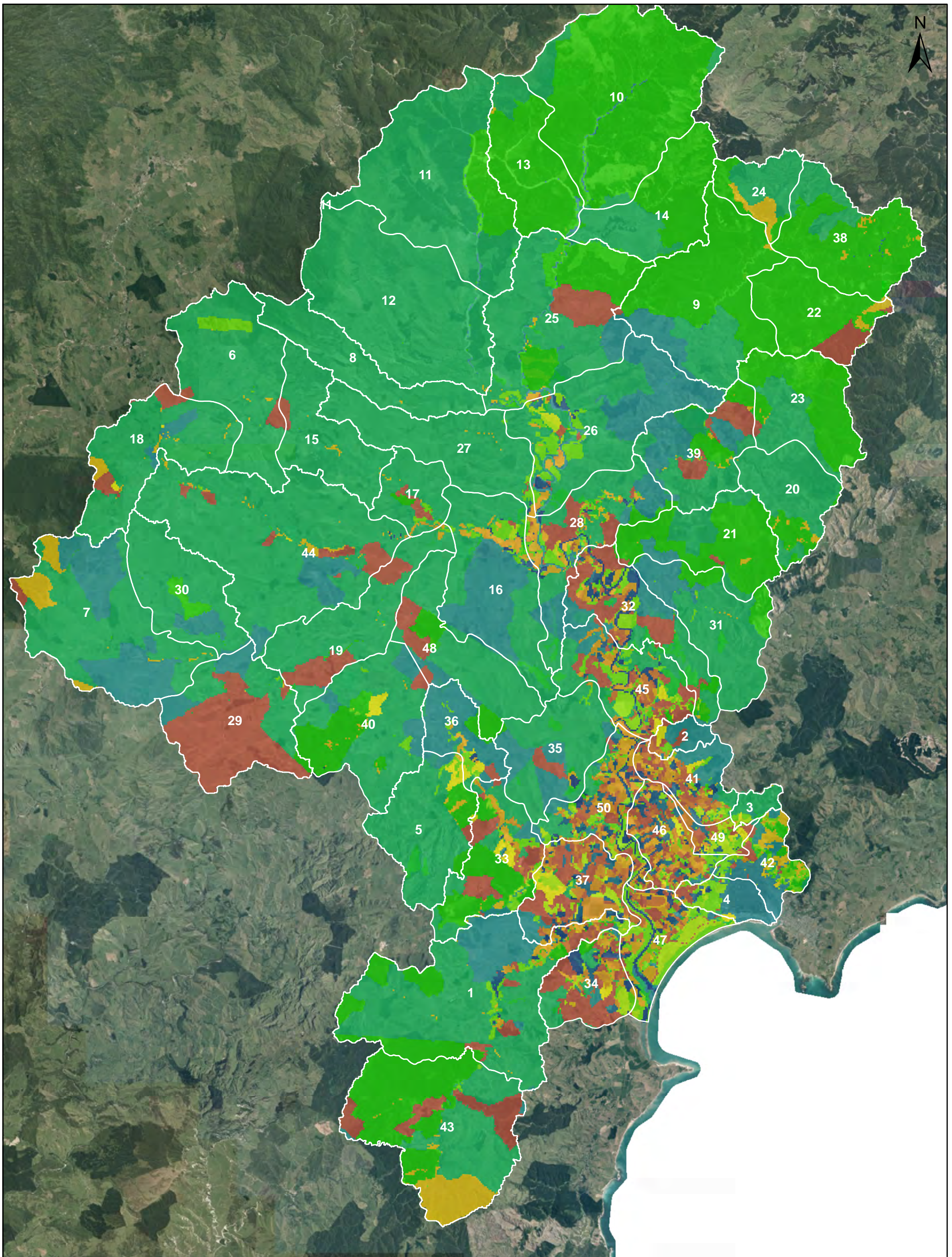
Waipaoa Catchment Sub Catchments

Figure A1

0 5 10 15 20 25 km

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JACOBS



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PROJECT Waipaoa Catchment Source Model	
SCALE 1:214,649	PROJECT CODE AE04830
PROJECT MANAGER JB	DRAWN JB
PROJECT DIRECTOR XX	DATE 5/07/2016

Functional Unit

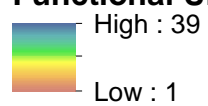


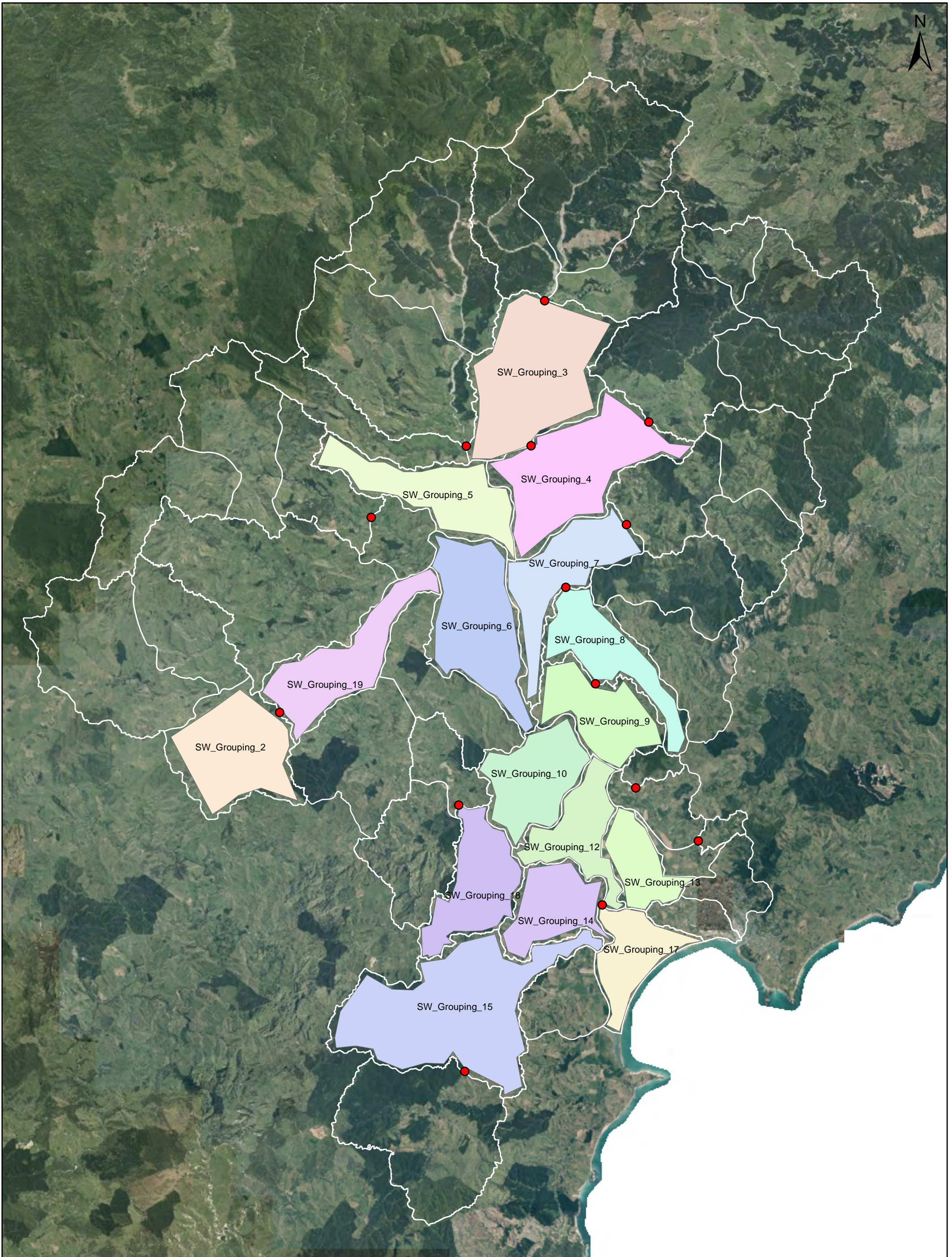
Figure A2

Waipaoa Sub-Catchments and Functional Units



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CLIENT GDC, Hort NZ	
PROJECT Waipaoa Catchment Source Model	
SCALE 1:229,443	@ A3
PROJECT CODE AE04830	
PROJECT MANAGER JB	DRAWN JB
PROJECT DIRECTOR XX	DATE 5/07/2016

● Monitoring Sites with Flow Records
 Waipaoa Catchment

Water Take Groups

Flow_Gauge_Catchments_Rev3_JB

Consented Water Takes

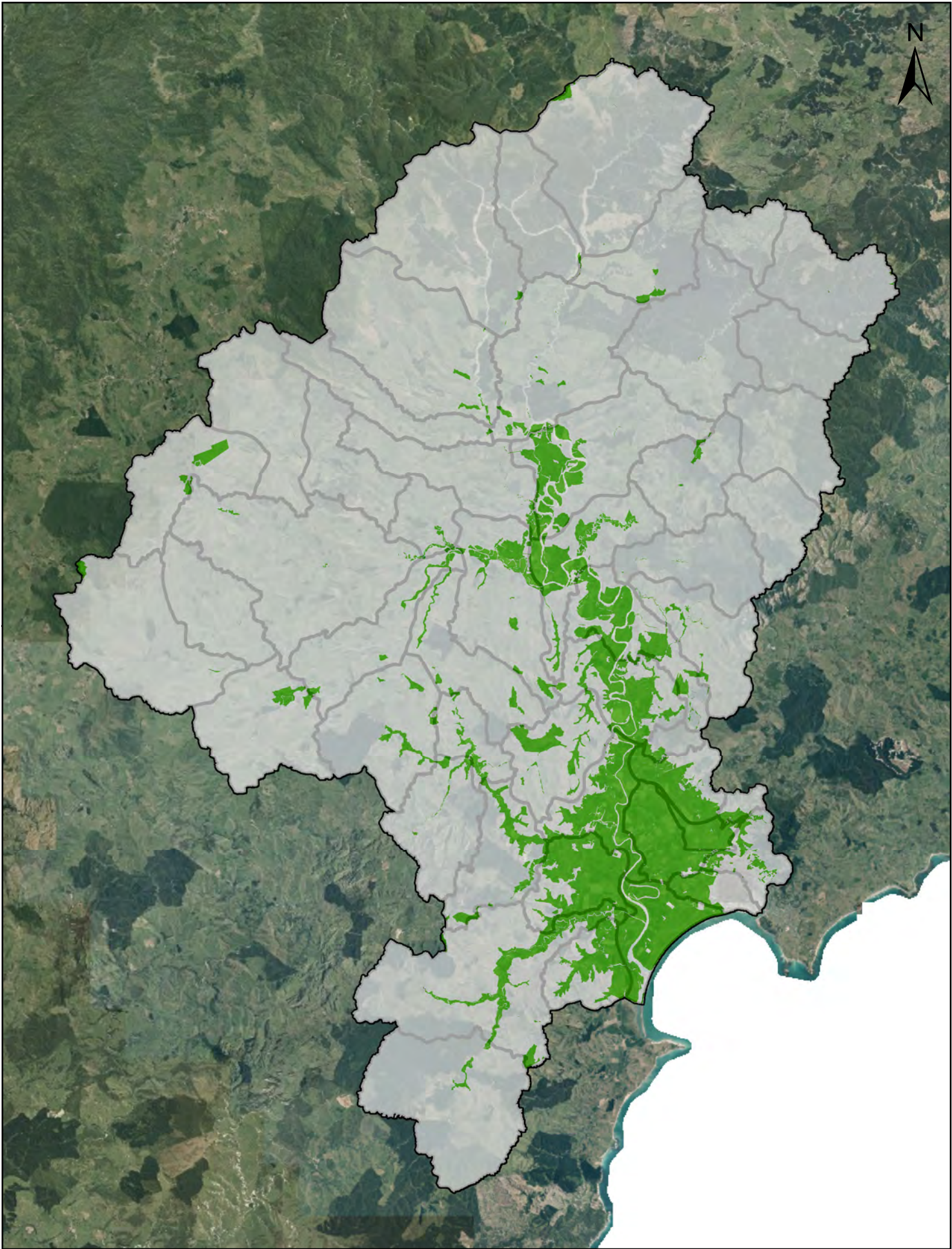
Surface Water Groupings of Consented Takes

Figure A3

0 5 10 15 20 25 km

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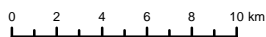
JACOBS



- Productive properties
- Properties on steeper land
- Source catchments

Waipaoa Catchment Productive Land

Figure A4



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Appendix B. Source calibrated parameters

Table B.1 : Soil Moisture Water Balance Model Input Parameters (limited values presented)

Functional Unit	FT	GL	PI	POW	ST	TL	ZmaxN	ZminN
Beef_PoorD	0.4	14.5	2.0	1.7	117.7	1.0	3.3	0.2
Beef_WellD	2.0	3.0	2.0	1.7	193.8	1.0	13.5	2.5
Citrus_PoorD_Irr	3.8	17.5	4.0	1.7	279.3	1.0	2.0	0.2
Citrus_PoorD	3.8	17.5	4.0	1.7	279.3	1.0	2.0	0.2
Citrus_WellD_Irr	5.9	2.8	4.0	1.7	300.0	1.0	10.1	2.5
Citrus_WellD	5.9	2.8	4.0	1.7	300.0	1.0	10.1	2.5
Grapes_PoorD_Irr	3.8	17.5	2.0	1.7	279.3	1.0	2.0	0.2
Grapes_PoorD	3.8	17.5	2.0	1.7	279.3	1.0	2.0	0.2
Grapes_WellD_Irr	5.9	2.8	2.0	1.7	300.0	1.0	10.1	2.5
Grapes_WellD	5.9	2.8	2.0	1.7	300.0	1.0	10.1	2.5
Maize_PoorD_Irr	3.8	17.5	2.0	1.7	279.3	1.0	2.0	0.2
Maize_PoorD	3.8	17.5	2.0	1.7	279.3	1.0	2.0	0.2
Maize_WellD_Irr	5.9	2.8	2.0	1.7	300.0	1.0	10.1	2.5
Maize_WellD	5.9	2.8	2.0	1.7	300.0	1.0	10.1	2.5
Native Forest_PoorD	4.0	10.0	4.0	1.7	216.8	1.0	2.4	0.2
Native Forest_WellD	6.5	1.8	4.0	1.7	230.0	1.0	14.9	2.5
Other_PoorD	0.4	14.5	2.0	1.7	117.7	1.0	3.3	0.2
Other_WellD_Irr	2.0	3.0	2.0	1.7	193.8	1.0	13.5	2.5
Other_WellD	2.0	3.0	2.0	1.7	193.8	1.0	13.5	2.5
Pasture_PoorD_Irr	0.4	14.5	2.0	1.7	117.7	1.0	3.3	0.2
Pasture_PoorD	0.4	14.5	2.0	1.7	117.7	1.0	3.3	0.2
Pasture_WellD_Irr	2.0	3.0	2.0	1.7	193.8	1.0	13.5	2.5
Pasture_WellD	2.0	3.0	2.0	1.7	193.8	1.0	13.5	2.5
Plantation Forest_PoorD	4.0	10.0	4.0	1.7	216.8	1.0	2.4	0.2
Plantation Forest_WellD	6.5	1.8	4.0	1.7	230.0	1.0	14.9	2.5
Sheep & Beef_PoorD_Irr	0.4	14.5	2.0	1.7	117.7	1.0	3.3	0.2
Sheep & Beef_PoorD	0.4	14.5	2.0	1.7	117.7	1.0	3.3	0.2
Sheep & Beef_WellD_Irr	2.0	3.0	2.0	1.7	193.8	1.0	13.5	2.5
Sheep & Beef_WellD	2.0	3.0	2.0	1.7	193.8	1.0	13.5	2.5
Sheep_PoorD_Irr	0.4	14.5	2.0	1.7	117.7	1.0	3.3	0.2
Sheep_PoorD	0.4	14.5	2.0	1.7	117.7	1.0	3.3	0.2
Sheep_WellD_Irr	2.0	3.0	2.0	1.7	193.8	1.0	13.5	2.5
Sheep_WellD	2.0	3.0	2.0	1.7	193.8	1.0	13.5	2.5
Urban	4.1	8.6	0.5	1.7	215.9	1.0	27.3	2.5
Vegetables_PoorD_Irr	3.8	17.5	2.0	1.7	279.3	1.0	2.0	0.2
Vegetables_PoorD	3.8	17.5	2.0	1.7	279.3	1.0	2.0	0.2
Vegetables_WellD_Irr	5.9	2.8	2.0	1.7	300.0	1.0	10.1	2.5
Vegetables_WellD	5.9	2.8	2.0	1.7	300.0	1.0	10.1	2.5
Waterbody	0	0	0	0	0	0	0	0

Table B.2 : Water quality input concentrations

Functional Units	DWC (leaching)			EMC (runoff)		
	NO ₃ mg/L	NH ₃ mg/L	DRP mg/L	NO ₃ mg/L	NH ₃ mg/L	DRP mg/L
Pasture_PoorD	3.29	0.024	0.006	0.16	0.21	0.04
Pasture_WellID	4.51	0.024	0.006	0.16	0.21	0.15
Maize_PoorD	6.67	0.027	0.006	1.30	0.12	0.13
Maize_WellID	9.55	0.027	0.006	1.30	0.12	1.17
Grapes_PoorD	1.24	0.027	0.006	0.10	0.12	0.02
Grapes_WellID	3.44	0.027	0.006	0.10	0.12	1.32
Citrus_PoorD	9.88	0.027	0.006	0.30	0.12	0.16
Citrus_WellID	12.00	0.027	0.006	0.30	0.12	1.54
Vegetables_PoorD	6.67	0.060	0.006	2.20	0.11	0.18
Vegetables_WellID	10.18	0.060	0.006	2.20	0.11	1.71
Native Forest	0.200	0.036	0.006	0.50	0.05	0.01
Plantation Forest	0.20	0.036	0.006	0.50	0.05	0.01
Urban	0.70	0.045	0.060	0.70	0.09	0.06
Sheep	0.130	0.024	0.006	0.70	0.03	0.05
Beef	0.130	0.024	0.006	0.70	0.03	0.05
Sheep/Beef	0.130	0.024	0.006	0.70	0.03	0.05
Other	0.130	0.057	0.006	0.70	0.03	0.05

Appendix C. Attenuation Reviews

Table C.1 : Denitrification Removal Literature Review

Paper	Model Type	Soil Type/Aquifer	Denitrification Removal (%)	Comment
Hantush & Wang 2003	MODFLOW MT3D Groundwater Model	Aquifer Sediments (sands/gravels underlain by silt/clay)	77	Combined reduction of 54%
		Riparian margins	23	
Jahangir et al. 2013	Monitoring wells (x30) and GW Sampling at 4 sites, well depths from 5-10 m and 20 m for bedrock trials	Low Permeability Sites (mod-poor drainage, silty clay)	46 to 77	Denitrification occurs in anaerobic soils, higher N ₂ O and Nitrates (NO ₃) in aerobic higher permeability soils that are unsaturated. Rainfall was ~864-1329 mm for 2 year study period
		High permeability Sites (well drained, sandy Clay, sandy Loam)	4 to 8	
Toda et al. 2002	Unknown	Shallow groundwater coastal agriculture Japan (4mbgl)	20	Referenced in Jahangir et al. 2013
Weymann et al. 2008	Unknown	Unknown	33 to 68	
Morgan et al. 2007	Nitrate loading of on-site wastewater systems in Oregon. Used MODFLOW 96 and MODFLOW MT3DMS. Very Complex study and very large area (3D model with over 5000 drilling logs, slug tests etc)	Sub-oxic shallow soils	37.6%- 78 % (Upper bound)	Complex Report, limited detailed outline of denitrification
Rassam et al. 2005	Riparian Zone Focus, Shallow GW. Complex model to be added as code to catchment models to calculate riparian denitrification. No specific % reductions	-	-	Active only in anoxic saturated part of the root zone. Higher soluble organic Carbon has a strong correlation with Denitrification
Smith et al. 2004	Tracer tests using injection sites and piezometers with multilevel samplers. Also mathematical tracer models	Shallow unconfined aquifer, depths from 4-14 m (multilevel assessments of denitrification)	36 to 43 % (N ₂ production as a function of N ₀₃ Generation)	No specific %, calculated from Abstract
Hadfield et al. 2007	Lake Taupo GW 3D Finite Model in steady state. Did not model denitrification, however looked at storage in the pores spaces which would eventually be slowly released at equilibrium.	3x aquifer units. No specific information on how much loading was occurring versus storage in aquifer (i.e. nothing to work out storage)	-	Porous space of 0.2-0.3 were used in the model. Fractured rock was 0.01-0.05.

Table C.2 : Stream/Reservoir attenuation of nutrients

Paper	Model Type	Stream/Reservoir Attenuation	Comment
Elliot et al. 2005	SPARROW Model statistical catchment model with decay functions modelled nitrogen and phosphorus loads through NZ, from Stream to source. This was calibrated with good/very good fit	TN= 55% TP= 56%	Attenuated in streams (predominantly) and reservoirs (less so). Calibrated well, and when no attenuation fit was poor. No discussion around what happens to this N and P besides being stored in river sediments, benthic etc and the model is built to try better understand what is being captured and building up in the system
IWA Conference 2010	Good overview paper of NZ research, no specific rates of attenuation provided		Attenuation occurs in streams receiving lateral flow from nutrients in groundwater and surface runoff adjacent to the stream, and streams with spring sources where nutrients are attenuated in the stream channel. source 1= Removed via riparian vegetation. source 2= instream attenuation (denitrification and microbes)
Wheeler & Elliot 2008	Overseer-CLUES Model for Waikato Region linked with SPARROW model regression analysis to develop best fits.	36 % for N only, (9-61% range)	
Elliot et al. 2014	Catchment models for nutrients, application to upper Waikato River Catchment for MOE. TP attenuation was taken from CLUES Model. Attenuation was applied for instream, groundwater (TN only) and hydro reservoirs. Range of factors applied to TN for attenuation.	45% (TN) (range 0-74%). TP ranged from 43-76% with a median of 59%. NATIONAL CLUES model average suggests 35% TN attenuation	20% adopted as min for TN, 30% as min for TP
Alexander et al. 2002	Referenced in Elliot et al. 2014	42%	Upper Waikato River Catchment, including reservoir attenuation
Downs et al. 1997	Referenced in Elliot et al. 2014	0-90 % for nitrate depending on riparian vegetation	Much of the removed nitrate is remobilised as other forms of nitrogen. Measured in a lake Taupo Catchment
Clothier et al. 2007	Referenced in Elliot et al. 2014	50% for TN	Manawatu River, includes a factor to convert TN to nitrate in this %. Largely based on CLUES modelling

Table C.3 : Nutrient leaching literature review

Paper	Description	Leaching data (kg/ha/yr)	
		N	P
Clothier <i>et al.</i> 2007	Developed a framework and produced best management practices for contaminant management on farms in the Manawatu-Wanganui region. Horizons Regional Council have identified the 4 intensive forms of farming as being dairying, irrigated sheep and beef, market gardening and cropping	Ranges from 6-60 (S&B), 15-115 (dairy), 10-140 (cropping), vegetables 100-300 kgN/ha/yr	0.1-1.6 (S & B), 0.2-1.0 (dairy) kgP/ha/yr
Landcare Research 2011	A national map of nitrate leaching (kg N/ha/yr) was produced from input maps of land use and stocking rates. The model was developed by running Overseer® for all soil and climate combinations in New Zealand (LENZ level II)	Annual rainfall = 1000 mm, N leached is ~0.5kg/ha/yr per stock unit. Higher rainfall (i.e. 2000 mm/yr), leaching increases to 1.5 kg/ha/yr/stock unit	-
Longhurst and Smeaton (2008) and Hungerford (2009)	Integrated catchment management for farms mostly on free draining soils in the Waikato Region. Used Overseer to derive nutrient budgets for 15 dairy farms. Greatest contribution to N loss was from stocking rates and fertilizer application	Mean N loss (dairy) was 45 kgN/ha/yr with ~1500 mm annual rainfall. Historical Drystock leaching estimated at 13 kgN/ha/yr	Mean P loss (runoff) was ~ 2.2kgP/ha/yr for 1500 mm rainfall

Paper	Description	Leaching data (kg/ha/yr)	
		N	P
Edmeades 2004	Inputs and outputs of nitrogen in Sheep and Beef and Dairy farms in the Waikato Region	37 kgN/ha/yr for dairy, 13 kgN/ha/yr for Sheep and Beef	-
Lilburn et al. 2013	Generate NNN leaching rate table for different landuses and soil types for the Canterbury Region, Nitrate losses and drainage values are taken from the Overseer® 6, LUCI and SPASMO modelling	11-25 for S & B non-irrigated, 11-22 for arable land, 0.4-0.6 for forests, 8-15 kgN/ha/yr for horticulture	-
Wheeler et al. 2013	OVERSEER® Nutrient Budgets modelling for the Tukituki catchment	26-38 for arable land, 11-16 for sheep and beef, 45-61 kgN/ha/yr for dairy	0.4-1 for arable land (runoff), 0.2-0.6 for S & B, 1.1-1.7 kgP/ha/yr for Dairy
Mackay et al. 2011	Eco efficiency of sheep and beef farms and their change over the last 20 years, using OVERSEER nutrient modelling including for the Gisborne region	7-9 for S & B, 1-5 for forestry, vegetables from 100-300 kgN/ha/yr	-
Parshotam, Elliot and Shankar 2013	National and regional nutrient mapping using the CLUES model, GIS based approach to assess the effects of land use change on water quality. Regional and national maps in kg/ha/yr were presented and values in tonnes/year	~4500 tonnes/year, assuming an area of 8361 km ² for Gisborne region, this would equate to 5.4 kgN/ha/yr (total load only, not just leaching data)	~11,500 tonnes/year, assuming an area of 8361 km ² , then average load of ~13.8 kgP/ha/yr (not just leaching data, total load)
Parfitt, Baisden and Elliot 2008	Review of the phosphorus budget for New Zealand at regional scales	-	Soluble P (DRP+DOP) in Gisborne was estimated to be ~200 tonnes/year, equivalent to 0.24 kgP/ha/yr
Gentile et al. 2014	Plant and Food Report for land management practices and nutrient losses in Poverty Bay developed through SPASMO modelling	Nitrate leaching of 10-19 kgN/ha/yr for a range of cropping types. Maize and Grapes had the lowest leaching of 5.2-6.6 kgN/ha/yr. Nitrate runoff (EMC) was minimal compared to leaching.	P runoff from 0.2-2.9 kgP/ha/yr for different cropping types, no leaching modelled
Manderson 2015	Nitrogen leaching estimates for sheep and beef in the Mangatainoka catchment, Horizons Regional Council. Utilisation of OVERSEER modelling	12.9 kgN/ha/yr average, higher leaching in catchments with higher annual rainfall	-
Parfitt et al. 2007	Best practice phosphorus losses from agricultural land, applied to the upper Manawatu water management zone. Used both OVERSEER and NZEEM models together	-	0.7 from sheep and beef and 0.9 kgP/ha/yr from dairy
Barlow et al. 2009	Assessed the transfer of nutrients at the catchment scale from different landuses using a Catchment Analysis Tool and an EMC/DWC approach to modelling water quality. Victoria, Australia.	Large range of values presented for many landuse types (forestry, dairy, pasture, cropping, irrigated horticulture etc) with both EMC and DWC values.	Large range of values presented for many landuse types (forestry, dairy, pasture, cropping, irrigated horticulture etc) with both EMC and DWC values.
Bartley et al. 2012	Review of sediment and nutrient concentration data in Australia for use in catchment water quality models. Extensive research paper with very large literature review presenting statistics (mean, median etc) for EMC/DWC concentrations on many different landuse types.	As above	As above

Appendix D. Marine Sediment Literature Review

The Waipaoa region is known to contribute some of the highest catchment sediment yields ever recorded (Hicks et al., 1996), which can substantially impact the delivery to rivers of high phosphorus loads bound to those sediments. A desktop literature review was conducted to assess the role of skeletal marine sediments on phosphorus contributions to the Waipaoa River (see Gibbs 2016 for a description on regional geology), as a primary source of sedimentation. The literature review focused on sourcing appropriate data or methods from which the relative contribution that these sediments may have to the observed phosphorus load, with a particular focus on Dissolved Reactive Phosphorus (DRP). This was at the request of Horticulture New Zealand.

Data was requested from the GDC library, the national archives and the national library. A number of papers and thesis on sediment related dynamics in the Waipaoa River were available, however there was limited information from which to determine the phosphorus contributions these sediments may have to river water quality.

Two key studies have been presented which used different methods to determine phosphorus loads.

The first is described by McDowell and Condon (2004) and Dymond *et al.* (2012), who assume most of the dissolved phosphorus is delivered by subsurface and overland flow. They utilised a method involving a simple equation relating DRP to the Olsen P (as a measure of plant available inorganic P) and P retention (% value, commonly called Anion Storage Capacity). The formula to estimate DRP (mg/L) is $0.069 \times \text{POlsen}/\text{PRet} + 0.007$ (Dymond *et al.* 2012)

There are limitations with this method as it often uses stocking rates to define Olsen P (where Olsen P data is unavailable), when the purpose of this literature review is to understand the background P load from marine sediments without human modification (i.e. in-situ soil P loads without farming practices).

This formula was applied to different soil types within the Gisborne region to derive estimates of DRP concentrations using soils described by the Fundamental Soil Layer (Landcare Research 2016). Some of the available soil data locations can be observed in Figure D.1.

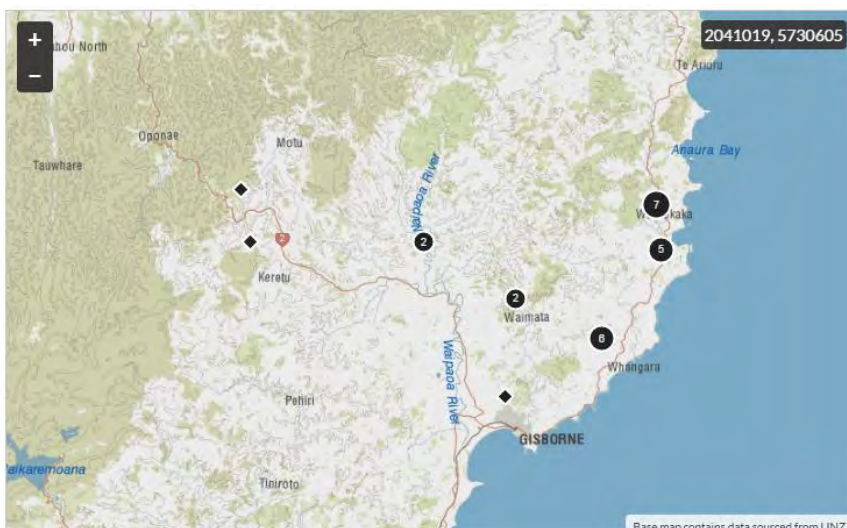


Figure D.1 : Fundamental Soils Layer showing locations where soil data exists around the Gisborne Region (Landcare Research 2016).

A number of the Fundamental Soils Layer data for P retention is presented in Table D.1. P retention is taken from the shallow soil layers (within 10 cm of the surface), consistent with comparable literature data presented for Gisborne. No data was available on Olsen P with these soil samples.

Table D.1 : P Retention of soils assessed for the Gisborne area (Landcare Research 2016).

Soil Classification	General Locality	P Retention (%)
SB10149	Upper Waipaoa Catchment	25
SB10146		24.5
SB10147	Upper/Mid Waipaoa Catchment	49
SB10148		39
SB10150	Mid Waipaoa Catchment	32.5
SB10152	Lower Waipaoa Catchment	27.5
Minimum		25
Average		34
Maximum		49

Review of additional literature data to determine acceptable minimum Olsen P values in the Gisborne region was undertaken, to determine potential DRP loads from Table D.1.

- Landcare Research (2016) provides indicative ranges for Indigenous Native NZ ecosystems where Olsen P levels of less than 8 would be considered normal.
- Olsen P test data is available for a range of Gisborne Hill Country sites from a research study through the 1980's (O'Connor and Gray 1984). They looked at a range of trial sites in the upper catchments with annual rainfall from 1500-1980 mm/year. Olsen P tests conducted in the top 10 cm ranged from 4-22 for different soil groups. 4 sites had Olsen P values of 4, 6, 7 and 9.
 - The lowest Olsen P (4 and 6) was identified at two sites which had no fertilizer application for 10 years and were sheep farms. These could be considered the most un-impacted soil types for use in estimating DRP.

Assuming the minimum-maximum P retention from Table D.1 and minimum Olsen P values from literature, DRP contributions from sediment has been further refined in Table D.2.

With attenuation of 60%, DRP generation from soils could range from 0.005 to 0.012 mg/L for the Waipaoa Catchment.

Table D.2 : Refined DRP concentrations (mg/L) using literature Olsen P

P Retention	DRP (mg/L)	Olsen P= 4	Olsen P= 6	Olsen P= 8
25	Baseline	0.018	0.024	0.029
	60% attenuation	0.007	0.009	0.012
33	Baseline	0.015	0.020	0.024
	60% attenuation	0.006	0.008	0.009
49	Baseline	0.013	0.015	0.018
	60% attenuation	0.005	0.006	0.007

Water quality data from 2003–2014 for three key sites (upper catchment to lower) was assessed for DRP to identify their average concentrations:

- Mahaki Station (upper catchment): 0.012 mg/L
- Kanakanaia Station (mid catchment): 0.010 mg/L
- Matawhero Station (lower catchment): 0.056 mg/L

The calculations in Table D.2 for an Olsen P of 4 and attenuation of 60% were compared against the average concentrations from each of the water quality stations outlined above. This can be seen in Table D.3.

Table D.3 : Proportion of DRP concentrations from natural sediment release (Olsen P=4, 60% attenuation)

Station	Average Concentration (mg/L)	P Retention 25%	P Retention 33%	P Retention 49%
Mahaki	0.012	60%	51%	42%
Kanakanaia	0.010	72%	61%	51%
Matawhero	0.056	13%	11%	9%
Average Proportion of Sediment DRP to average in stream concentrations		49%	48%	41%

The second study was undertaken by Parfitt, Baisden and Elliot (2008) whom reviewed the phosphorus budget for New Zealand at regional scales. The average annual P load in rivers across New Zealand is 1.6 kg/ha, with sediment-bound P the major component (this includes erosion, effluent and runoff). The weathering of P from soils in the Gisborne region was estimated at 1,900 tonnes P per year (for an 8,361 km² area). Gisborne was also identified as having some of the largest losses of P through erosion (10.2 kgP/ha) and burial (5.2 kgP/ha), higher than any of the other regions assessed and contributing to a total output of ~17.1 kgP/ha.

Inputs were estimated as 11.8kgP/ha/yr, which results in a negative annual balance of P for Gisborne (inputs versus outputs). DRP+DOP (Dissolved Organic Phosphorus) losses in soluble P runoff was approximated through an approach derived from N:P ratios, with Gisborne having a value of 200 tonnes/year. This was equivalent to ~0.24 kgP/ha/yr of soluble P losses (Parfitt, Baisden and Elliot 2008). The total annual river load for Gisborne was estimated to be 10.44 kgP/ha with the soluble load making up 2.3% (due to high erosion).

Equating these values to a concentration is approximate at best, given this is a regional based approach used to provide indicative annual totals with a number of assumptions in the calculations. For interest purposes, this has been undertaken assuming an annual average runoff in the lowlands area (from P & F report) of 125 mm/yr, and an equivalent value of 217 mm/yr for the upper catchments (see section 3.6.4). This would equate to soil soluble P runoff of ~0.19 and 0.11 mg/L.

Assuming a 60% attenuation (as applied in modelling), this would equate to in-stream DRP values of 0.08 mg/L and 0.04 mg/L for the lower and upper Waipaoa catchments. These values are considerably higher than the concentrations determined in Table D.2, further verifying the need for robust local studies within the Waipaoa Catchment.

A number of assumptions and generalisations have been undertaken to derive these estimates for both studies. These are a very broad indication only, and would need to be investigated through field studies, sampling and laboratory assessments. The values should be used with caution until ground studies verify otherwise. For example, adoption of a higher Olsen P value in the first method (i.e. Olsen P of 8, Table D.2) would consequently lead to sediment contributions in Table D.3 averaging between 50-80% of instream DRP load.

Appendix E. Scenario Results

Table E.1 : Scenario 1 Nitrate-N concentrations (mg/L)

Name of Node	NO ₃ -N mean annual load (t/y)		NO ₃ -N 95%ile concentration (mg/L)		NO ₃ -N Median (50th percentile) concentration (mg/L)		NO ₃ -N 5%ile concentration (mg/L)	
	Baseline	Double Irrig Area	Baseline	Sc1 - Double Irrig Area	Baseline	Sc1 - Double Irrig Area	Baseline	Sc1 - Double Irrig Area
Brunton Road Gauge	17.6	17.7	0.55	0.55	0.13	0.14	0.08	0.08
Kaiteratahi Bridge Gauge	447.6	448.9	0.49	0.49	0.08	0.08	0.03	0.03
Kanakanaia Gauge	422.1	422.9	0.49	0.49	0.08	0.08	0.02	0.02
Mahaki Gauge	53.1	53.1	0.56	0.56	0.09	0.09	0.02	0.02
Matawhero Gauge	492.2	495.5	0.49	0.49	0.09	0.10	0.03	0.03
Omapere Station Gauge	81.6	81.6	0.58	0.58	0.09	0.09	0.01	0.01
Rangimoe Gauge	36.0	36.0	0.54	0.54	0.08	0.08	0.01	0.01
Te Arai River at Pykes Weir	29.3	29.3	0.47	0.47	0.06	0.06	0.02	0.02
Terrace Station Gauge	44.5	44.5	0.41	0.41	0.04	0.04	0.02	0.02
Tuckers Road Gauge Taruheru	13.2	14.3	0.76	0.84	0.44	0.48	0.34	0.36
Waipaoa Station Gauge	45.6	45.6	0.34	0.34	0.04	0.04	0.02	0.02

Table E.2 : Scenario 1 Nitrate-N concentrations reflected as a % change

Name of Node	NO ₃ -N mean annual load (t/y)		NO ₃ -N 95%ile concentration (mg/L)		NO ₃ -N Median (50th percentile) concentration (mg/L)		NO ₃ -N 5%ile concentration (mg/L)	
	Baseline	Double Irrig Area	Baseline	Sc1 - Double Irrig Area	Baseline	Sc1 - Double Irrig Area	Baseline	Sc1 - Double Irrig Area
Brunton Road Gauge	-	0.34	-	0.27	-	1.3	-	1.51
Kaiteratahi Bridge Gauge	-	0.29	-	0.17	-	1.2	-	2.57
Kanakanaia Gauge	-	0.19	-	0.09	-	0.7	-	1.80
Mahaki Gauge	-	0.0	-	0.0	-	0.0	-	0.0
Matawhero Gauge	-	0.68	-	0.36	-	2.4	-	3.42
Omapere Station Gauge	-	0.0	-	0.0	-	0.0	-	0.0
Rangimoe Gauge	-	0.0	-	0.0	-	0.0	-	0.0
Te Arai River at Pykes Weir	-	0.0	-	0.0	-	0.0	-	0.0
Terrace Station Gauge	-	0.0	-	0.0	-	0.0	-	0.0
Tuckers Road Gauge Taruheru	-	8.47	-	9.75	-	8.5	-	7.97
Waipaoa Station Gauge	-	0.0	-	0.0	-	0.0	-	0.0

Table E.3 : Scenario 1 Dissolved Reactive Phosphorus concentrations (mg/L)

Name of Node	DRP mean annual load (t/y)		DRP 95%ile concentration (mg/L)		DRP Median (50th percentile) concentration (mg/L)		DRP 5%ile concentration (mg/L)	
	Baseline	Double Irrig Area	Baseline	Sc1 - Double Irrig Area	Baseline	Sc1 - Double Irrig Area	Baseline	Sc1 - Double Irrig Area
Brunton Road Gauge	0.9	0.9	0.031	0.032	0.008	0.008	0.006	0.006
Kaiteratahi Bridge Gauge	17.4	17.6	0.016	0.016	0.007	0.007	0.006	0.006
Kanakanaia Gauge	16.2	16.2	0.016	0.016	0.007	0.007	0.006	0.006
Mahaki Gauge	2.0	2.0	0.018	0.018	0.008	0.008	0.006	0.006
Matawhero Gauge	20.4	20.7	0.019	0.019	0.008	0.008	0.006	0.006
Omapere Station Gauge	2.9	2.9	0.018	0.018	0.008	0.008	0.006	0.006
Rangimoe Gauge	1.3	1.3	0.017	0.017	0.007	0.007	0.006	0.006
Te Arai River at Pykes Weir	1.0	1.0	0.013	0.013	0.007	0.007	0.006	0.006
Terrace Station Gauge	1.5	1.5	0.010	0.010	0.006	0.006	0.006	0.006
Tuckers Road Gauge Taruheru	0.9	0.9	0.076	0.082	0.013	0.014	0.006	0.007
Waipaoa Station Gauge	1.6	1.6	0.008	0.008	0.006	0.006	0.006	0.006

Table E.4 : Scenario 1 Ammonia-N concentrations (mg/L)

Name of Node	NH ₃ -N mean annual load (t/y)		NH ₃ -N 95%ile concentration (mg/L)		NH ₃ -N Median (50th percentile) concentration (mg/L)		NH ₃ -N 5%ile concentration (mg/L)	
	Baseline	Double Irrig Area	Baseline	Sc1 - Double Irrig Area	Baseline	Sc1 - Double Irrig Area	Baseline	Sc1 - Double Irrig Area
Brunton Road Gauge	1.4	1.4	0.038	0.038	0.013	0.013	0.011	0.011
Kaiteratahi Bridge Gauge	32.4	32.5	0.029	0.030	0.014	0.014	0.011	0.011
Kanakanaia Gauge	30.5	30.5	0.029	0.029	0.014	0.014	0.011	0.011
Mahaki Gauge	3.2	3.2	0.029	0.029	0.012	0.012	0.010	0.010
Matawhero Gauge	35.7	35.9	0.031	0.031	0.014	0.014	0.011	0.011
Omapere Station Gauge	4.5	4.5	0.027	0.027	0.012	0.012	0.010	0.010
Rangimoe Gauge	2.1	2.1	0.026	0.026	0.012	0.012	0.010	0.010
Te Arai River at Pykes Weir	2.4	2.4	0.030	0.030	0.014	0.014	0.012	0.012
Terrace Station Gauge	4.4	4.4	0.031	0.031	0.015	0.015	0.013	0.013
Tuckers Road Gauge Taruheru	1.3	1.4	0.093	0.100	0.020	0.022	0.012	0.013
Waipaoa Station Gauge	5.4	5.4	0.031	0.031	0.015	0.015	0.014	0.014

Table E.5 : Scenario 2 Nitrate-N concentrations (mg/L)

Name of Node	NO ₃ -N mean annual load (t/y)					NO ₃ -N 95%ile concentration (mg/L)					NO ₃ -N Median (50th percentile) concentration (mg/L)					NO ₃ -N 5%ile concentration (mg/L)				
	Baseline	25%	50%	75%	100%	Baseline	25%	50%	75%	100%	Baseline	25%	50%	75%	100%	Baseline	25%	50%	75%	100%
Brunton Road Gauge	17.6	18.0	18.3	18.7	19.0	0.55	0.56	0.57	0.58	0.58	0.13	0.14	0.15	0.16	0.17	0.08	0.09	0.09	0.10	0.11
Kaiteratahi Bridge Gauge	447.6	449.8	454.8	462.0	469.2	0.49	0.49	0.50	0.50	0.50	0.08	0.08	0.09	0.10	0.10	0.03	0.03	0.03	0.03	0.04
Kanakanaia Gauge	422.1	423.6	427.8	434.5	441.2	0.49	0.49	0.50	0.50	0.51	0.08	0.08	0.08	0.09	0.10	0.02	0.02	0.03	0.03	0.04
Mahaki Gauge	53.1	53.1	53.1	53.1	53.1	0.56	0.56	0.56	0.56	0.56	0.09	0.09	0.09	0.09	0.09	0.02	0.02	0.02	0.02	0.02
Matawhero Gauge	492.2	497.2	504.9	514.6	523.7	0.49	0.50	0.50	0.51	0.51	0.09	0.10	0.10	0.11	0.12	0.03	0.03	0.04	0.04	0.05
Omapere Station Gauge	81.6	81.6	81.6	81.6	81.6	0.58	0.58	0.58	0.58	0.58	0.09	0.09	0.09	0.09	0.09	0.01	0.01	0.01	0.01	0.01
Rangimoe Gauge	36.0	36.0	36.0	36.0	36.0	0.54	0.54	0.54	0.54	0.54	0.08	0.08	0.08	0.08	0.08	0.01	0.01	0.01	0.01	0.01
Te Arai River at Pykes Weir	29.3	29.3	29.3	29.3	29.3	0.47	0.47	0.47	0.47	0.47	0.06	0.06	0.06	0.06	0.06	0.02	0.02	0.02	0.02	0.02
Terrace Station Gauge	44.5	44.5	44.5	44.5	44.5	0.41	0.41	0.41	0.41	0.41	0.04	0.04	0.04	0.04	0.04	0.02	0.02	0.02	0.02	0.02
Tuckers Road Gauge Taruheru	13.2	14.7	16.2	16.8	17.2	0.76	0.83	0.89	0.92	0.93	0.44	0.49	0.55	0.56	0.57	0.34	0.37	0.44	0.44	0.46
Waipaoa Station Gauge	45.6	45.6	45.6	45.6	45.6	0.34	0.34	0.34	0.34	0.34	0.04	0.04	0.04	0.04	0.04	0.02	0.02	0.02	0.02	0.02

Table E.6 : Scenario 2 Nitrate-N concentrations reflected as a % change

Name of Node	NO ₃ -N mean annual load (t/y)					NO ₃ -N 95%ile concentration (mg/L)					NO ₃ -N Median (50th percentile) concentration (mg/L)					NO ₃ -N 5%ile concentration (mg/L)				
	Baseline	25%	50%	75%	100%	Baseline	25%	50%	75%	100%	Baseline	25%	50%	75%	100%	Baseline	25%	50%	75%	100%
Brunton Road Gauge	-	1.99	4.07	6.13	8.11	-	1.48	3.21	4.64	5.67	-	5.9	12.4	20.2	27.8	-	6.08	12.86	22.42	32.18
Kaiteratahi Bridge Gauge	-	0.50	1.60	3.22	4.82	-	0.31	1.23	2.20	2.99	-	1.9	6.5	15.4	24.0	-	4.63	15.94	36.09	54.25
Kanakanaia Gauge	-	0.35	1.34	2.93	4.50	-	0.21	1.15	2.17	2.98	-	1.4	5.7	15.1	24.0	-	3.81	15.08	36.53	55.59
Mahaki Gauge	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.0	0.0	0.0	0.0	-	0.00	0.00	0.00	0.00
Matawhero Gauge	-	1.01	2.60	4.54	6.40	-	0.72	1.95	3.11	4.07	-	3.5	9.8	20.4	30.5	-	5.86	17.65	35.66	51.72
Omapere Station Gauge	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.0	0.0	0.0	0.0	-	0.00	0.00	0.00	0.00
Rangimoe Gauge	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.0	0.0	0.0	0.0	-	0.00	0.00	0.00	0.00
Te Arai River at Pykes Weir	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.0	0.0	0.0	0.0	-	0.00	0.00	0.00	0.00
Terrace Station Gauge	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.0	0.0	0.0	0.0	-	0.00	0.00	0.00	0.00
Tuckers Road Gauge Taruheru	-	11.5	23.30	27.4	30.70	-	8.97	16.05	20.01	22.13	-	10.5	24.3	26.4	29.1	-	10.92	29.18	31.51	35.28
Waipaoa Station Gauge	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.0	0.0	0.0	0.0	-	0.00	0.00	0.00	0.00